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An Investigation of Corrosion in Particulate Control Equipment

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16. ABSTRACT

This document presents the results of an investigation of corrosion problems in particulate control equipment. During the investigation, corrosion problems in 38 fabric filters, wet scrubbers and electrostatic precipitators were observed and 7 control equipment manufacturers were interviewed. The document also contains guidelines to assist control equipment users and enforcement personnel in reducing particulate emissions resulting from corrosion-related malfunctions. Key parameters discussed include scrubber liquor composition, materials selection, the sulfuric acid dewpoint, and thermal insulation. Controlled particulate emissions sources discussed include rotary dryers and kilns, cupolas, incinerators, and steam boilers.

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An Investigation of Corrosion in Particulate Control Equipment

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CONVERSION FACTORS

1 meter (m) = 3.281 ft

1 meter (m) = 39.37 in.

1 $meter^2$ (m^2) = 10.76 ft^2

1 $meter^3$ (m^3) = 35.31 ft^3

1 $meter^3$ (m^3) = 1000 liter (ℓ)

1 $metre^3$/second (m^3/s) = 2.119×10^3 ft^3/min (cfm)

1 liter (ℓ) = 0.264 gal (U.S. liquid)

1 kilogram (kg) = 2.205 lb

1 kilogram (kg) = 1.102×10^{-3} short tons (2000 lb)

1 megagram (Mg) = 1.102 short tons (2000 lb)

1 joule (J) = 9.471×10^{-4} Btu (mean)

1 joule (J) = 2.778×10^{-7} kWh

1 watt (W) = 1.341×10^{-3} hp

1 pascal (Pa) = 1.450×10^{-4} $lb_f/in.^2$ (psi)

1 pascal (Pa) = 4.019×10^{-3} in. of H_2O (60°F)

1 kilopascal (kPa) = 0.01036 atmospheres (Atm)

1 kilopascal (kPa) = 4.019 in. of H_2O (60°F)

Degrees Celsius = (degrees Fahrenheit - 32) ÷ 1.8

Degrees Kelvin = degrees Celsius + 273.15

SECTION 1

INTRODUCTION

The Division of Stationary Source Enforcement (DSSE) of the U.S. Environmental Protection Agency is concerned about malfunctions in particulate control equipment at stationary sources that result in violations of emissions regulations. Previous studies have led DSSE to believe that corrosion is one of the leading causes of these malfunctions. DSSE conducted this study to provide to agency personnel and control equipment users background information on corrosion and guidelines for avoiding such corrosion.

BACKGROUND INFORMATION

In 1978 the President's Council on Environmental Quality conducted a survey to identify the causes of excess emissions from controlled stationary sources that had initially been in compliance with emissions regulations. Inspection of 20 such sources showed that corrosion-related malfunctions in the control equipment were the primary cause of excess emissions at 3 sources and contributing causes at 6 sources.[1] Subsequent source inspections conducted for DSSE confirmed that corrosion is a common cause of malfunction in particulate control equipment.[2] These inspections also revealed that many sources do not devote sufficient attention to corrosion control when they select particulate control systems. In many cases proper corrosion control measures have been determined by trial and error at great expense (Figure 1). In addition, the transfer of knowledge gained in this manner is often slow, allowing mistakes to be repeated in subsequent applications.

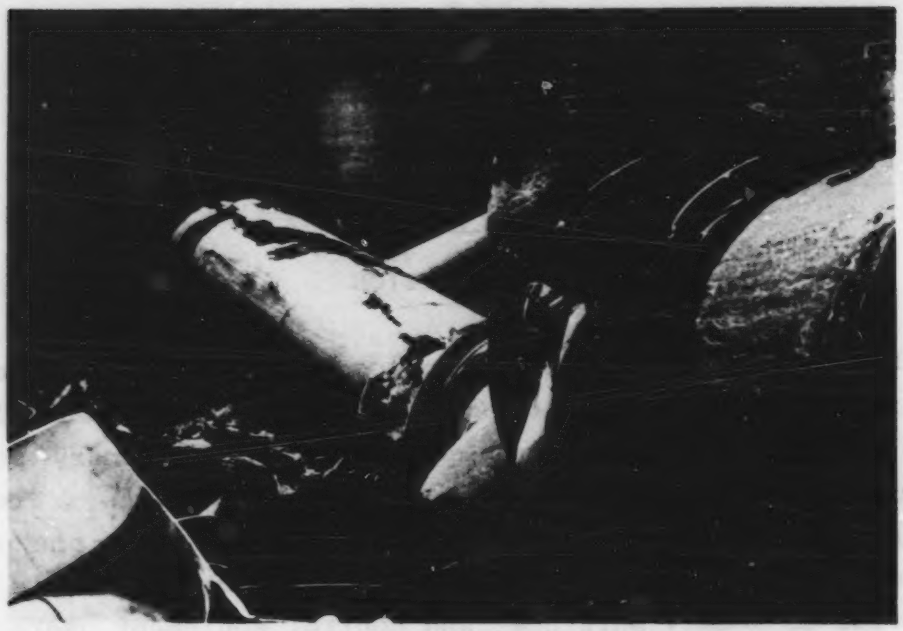

Figure 1. Wire-burning incinerator scrubber that was totally destroyed by corrosion.

Based on these results, DSSE saw a need to assist particulate control equipment users and State Enforcement Agency personnel in coping with corrosion problems. They commissioned this study to characterize the effects that corrosion can have on the performance and operating life of particulate control equipment and to assemble guidelines to help reduce the frequency and severity of excess emissions incidents due to corrosion. They hoped such guidelines would also help reduce costs attributable to corrosion by encouraging the use of more reliably designed equipment.

DESCRIPTION OF THE STUDY

The study included four phases. The initial phase was a review of technical literature to determine the extent of knowledge on corrosion in particulate control equipment. Information obtained by a computerized search of engineering and environmental indexes at the Air Pollution Technical Information Center of the Office of Administration, Information Services Division, U.S. EPA, Research Triangle Park, North Carolina, was supplemented with information from other sources and summarized in an indexed bibliography.

The second phase of the study was the identification of particulate emissions sources where control equipment corrosion was known to be a problem. Most of these candidate facilities were identified through the assistance of State Agency field inspectors.

The third phase of the study was the inspection of a sampling of the identified sources to gain first hand information about specific corrosion problems. This phase involved the inspection of 38 control devices at 18 facilities, all of which participated voluntarily. To help elicit honest and complete responses from personnel at these facilities it was agreed before-hand that neither facility names nor identifying process information would be listed in this report. Several facility managers insisted that no photographs be taken within their facilities before agreeing to participate.

The final phase of the study consisted of a series of interviews with design engineers at seven manufacturers of particulate control equipment. As in the case of the emissions sources, these manufacturers are not identified in this report.

Section 2 of this report lists the principal findings of the various phases of this study. Section 3 describes common modes of corrosion reported in the literature, observed during the study, or reported by the equipment manufacturers. Section 4 discusses the possible effects of process characteristics and plant operation and maintenance practices on control equipment corrosion. Section 5 presents guidelines for avoiding corrosion in particulate control equipment. The appendices include inspection reports for each of the 18 facilities inspected during the study and the indexed bibliography about corrosion in particulate control equipment. The inspection reports are referenced as examples in the following sections of the text.

SECTION 2

SUMMARY OF FINDINGS

This section lists eight major findings of the study. Some of the findings are illustrated by the case histories described in the Appendix A inspection reports. References are made, therefore, to these inspection reports where appropriate.

1. The study confirmed that corrosion in air pollution control equipment is a common underlying cause of equipment malfunction. In some cases, corrosion has led to surprisingly rapid destruction of control equipment. (See Appendix A, Sources 12 and 17). In other cases, less severe corrosion has resulted in lower particulate removal efficiency or decreased system reliability.

2. Literature addressing corrosion in particulate control equipment is beginning to appear in technical journals (see Appendix B). Numerous papers and reports have been published about operation and maintenance problems, including corrosion, in particulate control equipment at municipal incinerators. Several papers have also been published about similar problems in equipment serving various iron and steel industry processes, industrial and utility boilers, pulp and paper mills, and cement plants. In addition, two seminars have been held about corrosion in air pollution control equipment. These were sponsored jointly by the National Association of Corrosion Engineers, the Industrial Gas Cleaning Institute, and the Air Pollution Control Association.

   Certain problems observed during the plant visits of this study or cited by the control equipment manufacturers have not been addressed adequately in the literature. These include corrosion in equipment serving the primary and secondary nonferrous metals industries, lime kilns, crushed aggregate dryers, and the phosphate fertilizer industry; pH control in scrubbers; and the relationship of wet quenching to dewpoint corrosion.

3. Corrosion can increase particulate emissions at controlled sources. In some cases corrosion has completely destroyed the control equipment, resulting in extended periods of uncontrolled emissions (Source 17). In other cases corrosion has resulted in frequent short-term use of bypass stacks during periods of malfunction (Sources 6 and 13). Some control equipment remains operational after suffering corrosion damage, but the particulate removal efficiency is often reduced by the corrosion (Sources 11, 12, 14, and 16).

4. Corrosion-related system failures often add significant, unexpected costs to the operation of the controlled process. These failures sometimes neccessitate replacement of expensive capital equipment long before the end of its designed life (Sources 1, 2, 6, 10, 12, 14, 17, and 18), cause substantial increases in maintenance costs (Sources 4, 5, 7, 15, and 16), or cause substantial loss-of-production costs at facilities where the regulations do not permit uncontrolled emissions during repair of control equipment (Source 13).

5. Several recurring causes are responsible for most of the corrosion problems in control equipment: poor control of flue gas temperature, which leads to acid dewpoint problems (Sources 5, 6, 7, 9, 10, 12, and 16); inappropriate materials of construction and/or poor pH control in scrubbers (Sources 1, 8, 13, 17, and 18); and the combined effects of corrosion and abrasion (Sources 15 and 16). Acids derived from sulfur oxides and nitrogen oxides are the most common agents responsible for corrosion. Chlorides are also a common cause of corrosion.

6. Particulate control devices that seem to be particularly susceptible to corrosion are those serving cast iron cupolas, municipal incinerators, coal-fired boilers, lime kilns, cement kilns, rotary aggregate dryers, nonferrous-metals industries, and the phosphate fertilizer industry.

7. **Most of the corrosion failures observed during the study could have been prevented or reduced in severity by application of existing technologies. In many cases the sources selected inappropriate equipment designs because of inexperience or because of a perceived cost savings. Poor operating practices have also contributed to corrosion in some cases. Scrubber manufacturers indicated that a major problem in scrubber design is the frequent inability of sources to provide complete process information when ordering particulate scrubbers. The manufacturers claim that scrubbers can generally be designed to withstand corrosive environments if all corrosive constituents affecting the scrubbers are identified prior to design. Many scrubber users do not provide chemical analyses of the raw materials, flue gases, or scrubbing waters to the manufacturers.**

8. **The findings in 7 indicate that the need is not as great for further research as it is for a more effective application of existing technologies. Research could be beneficial in a few areas, however. One such area is the development of fuel cost models to compare the costs of increasing process temperatures with potential benefits derived from reducing dewpoint corrosion. The cement industry is a good candidate for this type of study. Another area is the analysis of pH control systems to identify features that could improve system reliability. The emphasis of such research should be to develop pH control systems that can be properly maintained at small sources with small, poorly trained staffs. Finally, it may be beneficial to run a series of in situ tests of various alloys and protective coatings in a variety of corrosive control equipment applications. Tests such as these would increase knowledge about the behavior of materials used in various control equipment environments.**

SECTION 3

MODES OF CORROSION IN CONTROL EQUIPMENT

Despite the wide variety of particulate sources and the numerous designs and configurations of particulate control devices, only a few modes of corrosion are responsible for most failures reported in this study. These modes include acid dewpoint corrosion, corrosion by scrubbing liquors, and erosion-corrosion (or abrasion). Each of these modes is described in detail below.

ACID DEWPOINT CORROSION

Acid dewpoint corrosion is the predominant mode of corrosion in fabric filters and electrostatic precipitators (ESP's) serving hot sources. The acid dewpoint generally refers to the temperature at which sulfur trioxide vapor (SO_3) will combine with water vapor to form sulfuric acid (H_2SO_4). Sulfur trioxide is found most frequently in flue gases produced by processes using sulfur-bearing fuels such as coal, coke, and oil. Sulfur trioxide can also be formed in primary metals-refining processes, such as copper smelting, because the ores typically contain large quantities of sulfur.

Combustion of sulfur-bearing fuel first results in the formation of sulfur dioxide (SO_2); some of this SO_2 is further oxidized to SO_3. The exact amount of SO_2 converted to SO_3 is dependent on many variables including gas temperatures in the combustion zone, the configuration of the combustion chamber, the availability of oxygen in the flame, and the concentrations of impurities such as vanadium which can act as catalysts.[3]

Sulfur trioxide and water have a strong affinity for each other; when temperatures are lowered to the dewpoint the two combine rapidly to form sulfuric acid molecules. The sulfuric acid molecules in turn have a high affinity for water. As they condense they draw additional water molecules from the gas stream forming a concentrated acid solution. Therefore, when flue gases containing relatively small concentrations of SO_3 reach the dewpoint temperature, droplets of concentrated sulfuric acid can condense on the cooler surfaces. For example, an 82.5 percent sulfuric acid solution (by weight) will condense at 148°C from flue gases containing as little as 40 ppm (by volume) SO_3 and 10 percent (by volume) water vapor.[4] Most fabric filter and ESP enclosures and much of their internal hardware are constructed of mild steel, which is very susceptible to sulfuric acid attack.

After review of available data, Verhoff and Banchero developed an empirical relationship from which the dewpoint temperature can be calculated when the percentages of water vapor and sulfur trioxide are known (Equation 1).[5]

$$T_{DP} = \frac{1,000}{1.7842+0.269\log P_{H_2O}-0.1029\log P_{SO_3}+0.0329\log P_{H_2O}\log P_{SO_3}} \qquad \text{(Eq. 1)}$$

where

T_{DP} = dewpoint temperature in degrees kelvin

P_{H_2O} = vapor pressure of water in atmospheres

P_{SO_3} = vapor pressure of sulfur trioxide in atmospheres.

This equation has agreed with most experimental results to within about 7 degrees kelvin. In cases where measurement or estimation of SO_3 and water vapor concentrations is not practical, gross estimates of the dewpoint can be based on sulfur content of the fuels.[6] In either case it is advisable to add a factor of safety to the estimated dewpoint temperature to allow for variations in flue gas composition and to compensate for nonuniform flue gas temperatures throughout the system.

Acid dewpoint corrosion is most likely to occur in locations where flue gas temperatures are the coolest or where steel surfaces are the coolest. Temperatures in dust hoppers are often cooler because gas detention is longer than at other locations (which allows more time for cooling) and because the hoppers have a large surface-to-volume ratio (which increases the rate of radiant heat loss to ambient air). Thus, hoppers without properly designed heaters or insulation are frequently affected by acid dewpoint corrosion (Figure 2). Outer walls (especially corners) of a filter or an ESP are other locations that are often cooler and subject to acid dewpoint corrosion (Figures 3 and 4). Entry hatches and hatch frames are also more likely to corrode because of cool air inleakage and because the hatches are often not as well insulated as the rest of the structure (Figure 5).

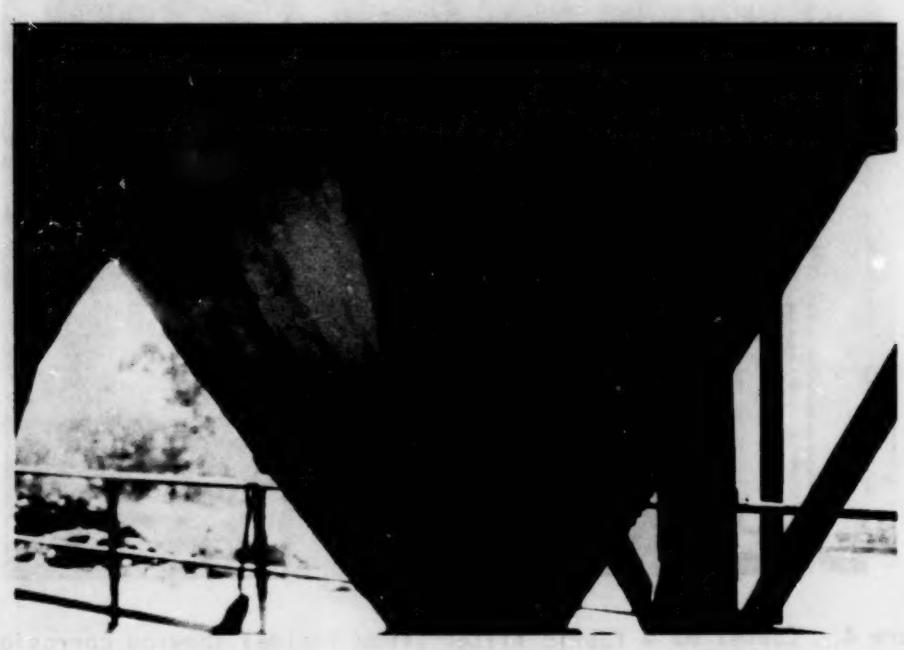

Figure 2. Uninsulated fabric filter dust hopper with with a patch over area of corrosion penetration.

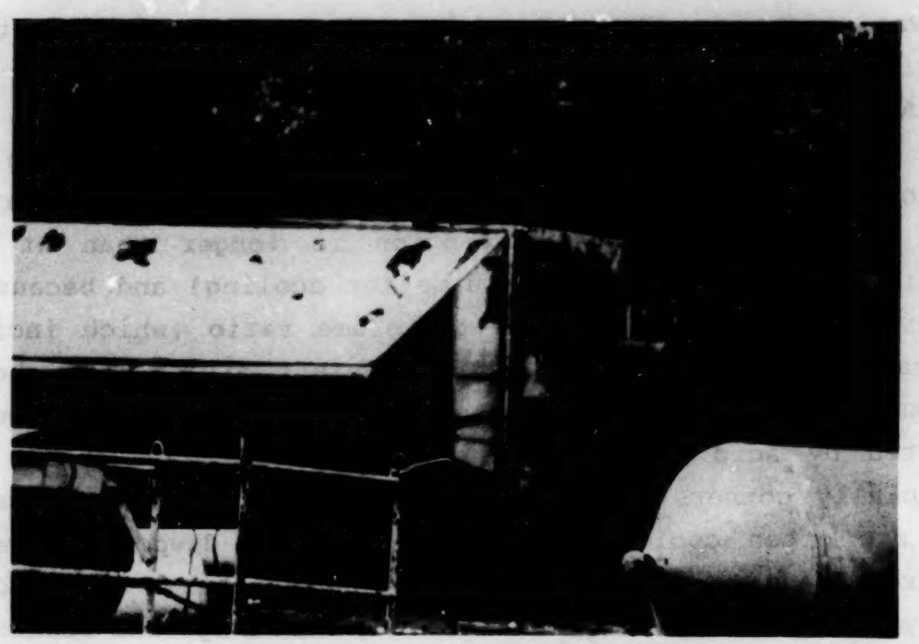

Figure 3. Cast iron cupola fabric filter that was scrapped after 5 years of service because of corrosion.

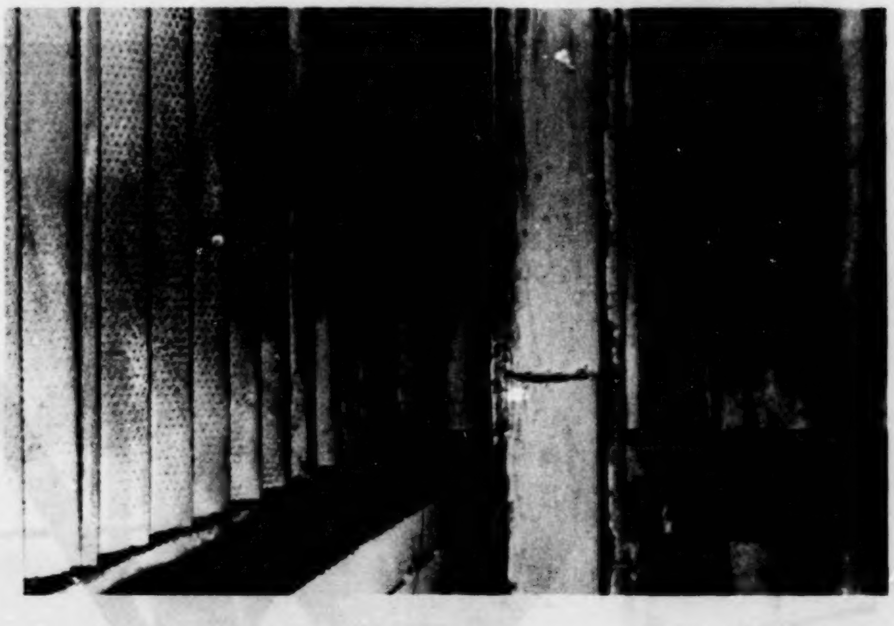

Figure 4. Corner of a fabric filter (from inside) showing corrosion of mild steel structure. Note that new horizontal beams have been welded to existing beams to reinforce corroded beams.

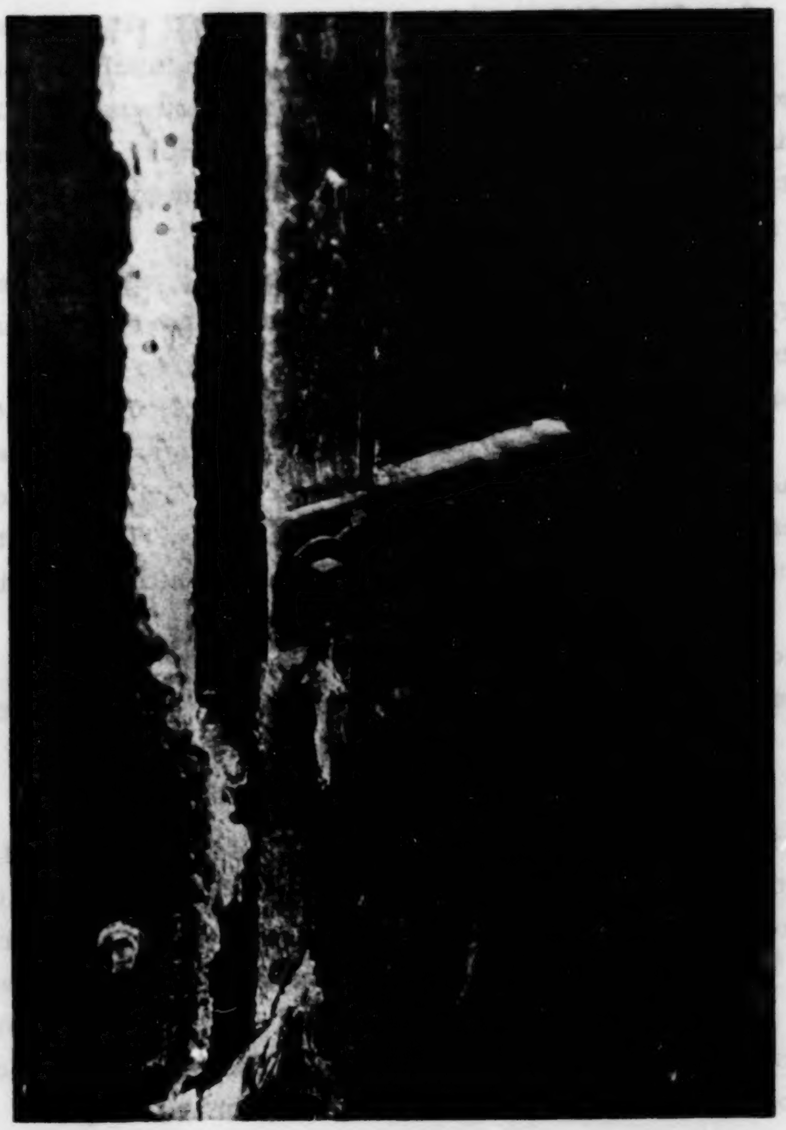

Figure 5. Corrosion damage to the frame of an uninsulated entry hatch in a fabric filter.

Components that suffered from acid dewpoint corrosion in the 11 fabric filters studied include dust hoppers (Sources 5-7, 16), sidewalls and corners (Sources 5-7, 12, 14, 16), entry hatches (Sources 9, 12, 14), bag hangers and other bag hardware (Sources 9, 12, 16), filter compartment isolation dampers (Sources 11, 16), and "top end" components such as bag support structures and bag cleaning mechanisms (Sources 9, 11). Five fabric filter manufacturers reported that dust hoppers, top end components, and bag hardware are the components most frequently affected by corrosion.

ESP enclosures are subject to cooling effects similar to those affecting fabric filter enclosures; therefore, many corrosion problems reported in fabric filters also appear in ESP's. As in fabric filters, acid dewpoint corrosion often attacks dust hoppers, corners of the enclosures, access hatches, hatch frames, and the undersides of roof plates. It can also occur in penthouses that contain support insulators. At installations where flue gas temperatures are very low, acid dewpoint corrosion can attack structures within the ESP, such as discharge plates and discharge wires. Examples of acid dewpoint corrosion in ESP components are described in the Source 10 report.

CORROSION BY SCRUBBING WATERS

The interaction of process gases and scrubbing liquids in particulate scrubbers very often creates liquors that are extremely corrosive. Unlike acid dewpoint corrosion, corrosion by scrubbing waters may involve a wide variety of corrosive agents, including sulfuric acid, hydrochloric acid, hydrofluoric acid, nitric acid, organic acids, metallic salts, and others. The presence of these agents causes many scrubbing liquors to have a very low pH level and/or a high level of dissolved solids, both of which tend to cause corrosion in metals. Stainless steels and high nickel alloys, which are resistant to corrosion in many acid solutions, can suffer corrosion in scrubber service because of the synergistic effects of chlorides or fluorides with acids in the liquors.

Corrosion by scrubbing waters can manifest itself in a variety of forms. The most common of these are listed below.

Uniform Attack

Uniform attack commonly occurs when mild steel is exposed to an acid, such as sulfuric acid. Uniform attack is not limited to mild steels, however, and it can be caused by a variety of corrosive agents.

Pitting

Pitting is a localized form of corrosion that results in holes in the surface of the exposed metal. After pit initiation, rapid perforation of the metal can occur although surrounding surfaces remain relatively unaffected by corrosion (Figure 6). Most pitting of scrubber components results because of high levels of chlorides in the scrubbing liquors.[7] The Source 1 report describes a case of severe pitting in the stainless steel walls of a scrubber vessel which resulted because of chlorides in the scrubbing liquor.

Figure 6. Pitting of stainless steel in a municipal incinerator scrubber vessel.

Crevice Corrosion

Crevice corrosion is the localized corrosion of a metal surface within crevices or other shielded areas exposed to corrosive liquids. The corrosion rate is often accelerated in a crevice because the concentrations of oxygen and metallic ions in the relatively stagnant fluid within the crevice can differ greatly from concentrations in the more turbulent fluid outside the crevice. Potential sites for crevice corrosion in scrubbers include bolts and other mechanical fasteners, incompletely welded seams (e.g., skip welds and one-sided butt welds), and holes or tears in coatings and linings. The Source 1 and Source 2 reports describe corrosion in scrubbing liquor recirculation pumps which occurred in crevices under tears in their linings.

Stress Corrosion

Stress corrosion is a particularly serious form of deterioration caused by the simultaneous effects of tensile stress and corrosion (Figure 7). Various metals can suffer the effects of stress corrosion cracking dependent on the corrosive agents present. Austenitic stainless steels are most likely to suffer stress corrosion cracking in chloride environments. The Source 1 and Source 2 reports describe stress corrosion cracking of high nickel alloy fans serving municipal incinerator scrubbers.

Weld Decay

Weld decay is the corrosion of a normally resistant metal in the vicinity of a weld (Figure 8). Weld decay occurs in stainless steels because the heat involved in the welding process can cause chromium in the alloy to precipitate with carbon to form insoluble carbide particles within the affected areas of the metal. The lowered chromium content of the metal remaining in these sensitized areas reduces the metal's resistance to corrosion. Examples of weld decay are described in the Source 1 and Source 3 reports.

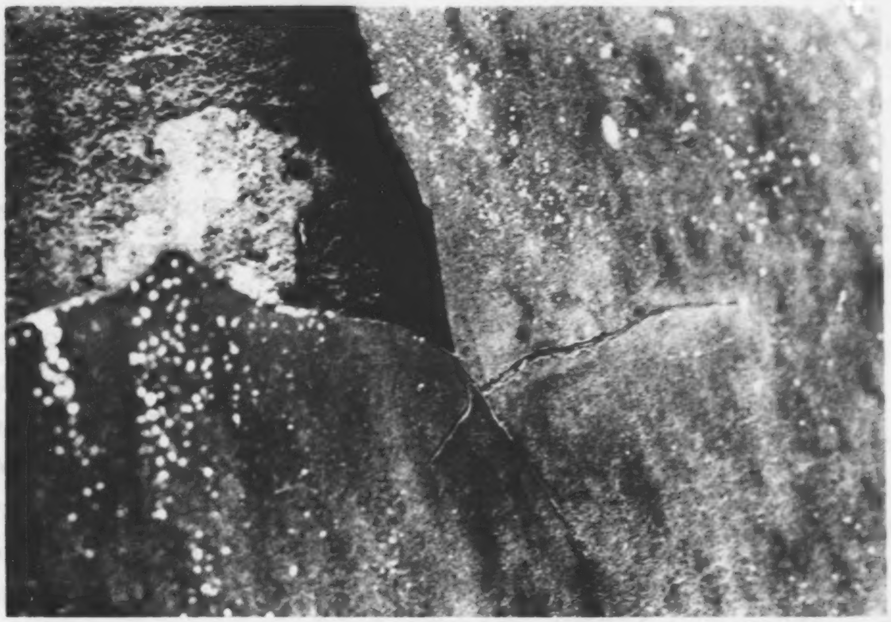

Figure 7. Stress corrosion cracking of stainless steel ductwork of a sewage sludge incinerator scrubber.

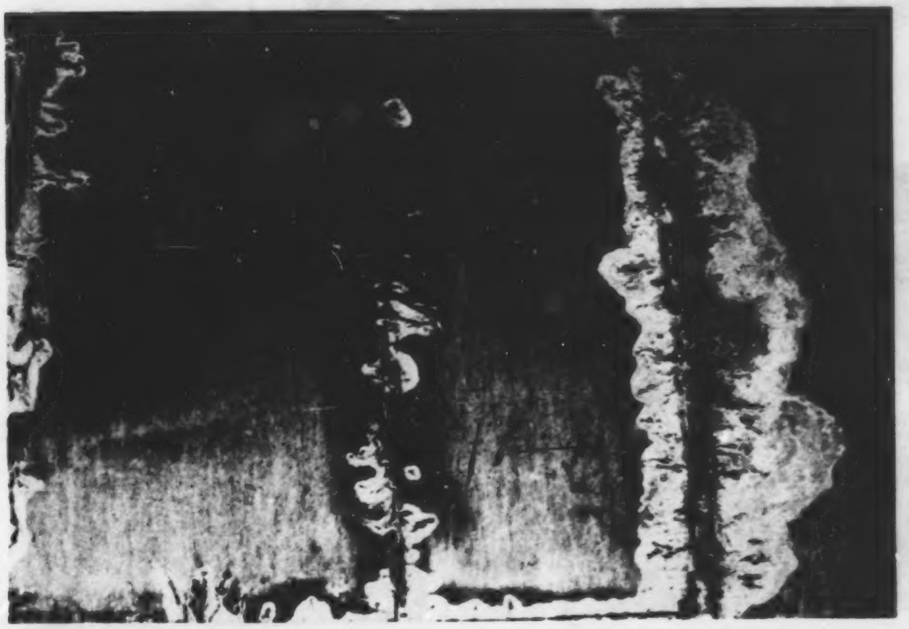

Figure 8. Weld decay in stainless steel ductwork of a sewage sludge incinerator scrubber; outleakage has caused additional corrosion on the exterior surfaces.

EROSION-CORROSION

Erosion-corrosion is the third mode of corrosion commonly found in particulate control equipment. Erosion-corrosion is an acceleration of corrosive attack due to the removal of otherwise protective oxide films by suspended abrasive particulate. By this removal, fresh metal is continually exposed to the corrosive medium. Erosion-corrosion is most likely to occur at points where flue gases, sprays, or scrubbing liquids must make sudden changes in direction, e.g., at elbows, at the inlet to cyclonic mist eliminators (Figure 9), and at blast plates in fabric filters. Erosion-corrosion also can occur in the turbulent zones of venturi scrubbers and in fans (Figure 10). Source reports 2, 15, and 17 describe erosion-corrosion failures in scrubber vessels and Source reports 5, 7, and 16 describe abrasive failures of fans.

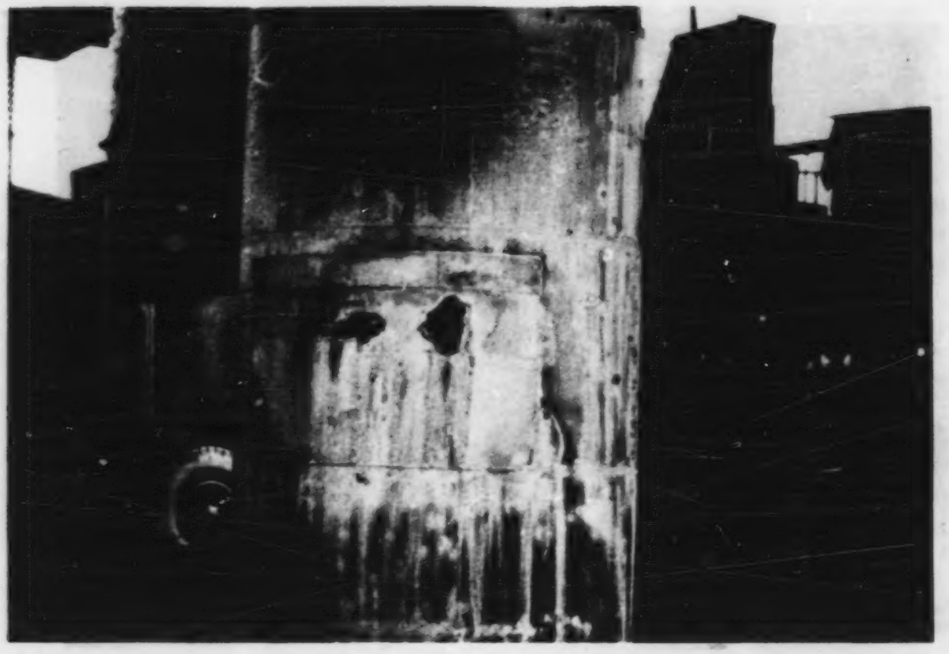

Figure 9. Erosion-corrosion at the inlet of a cyclonic mist eliminator of a venturi scrubber serving a hot-mix asphalt plant.

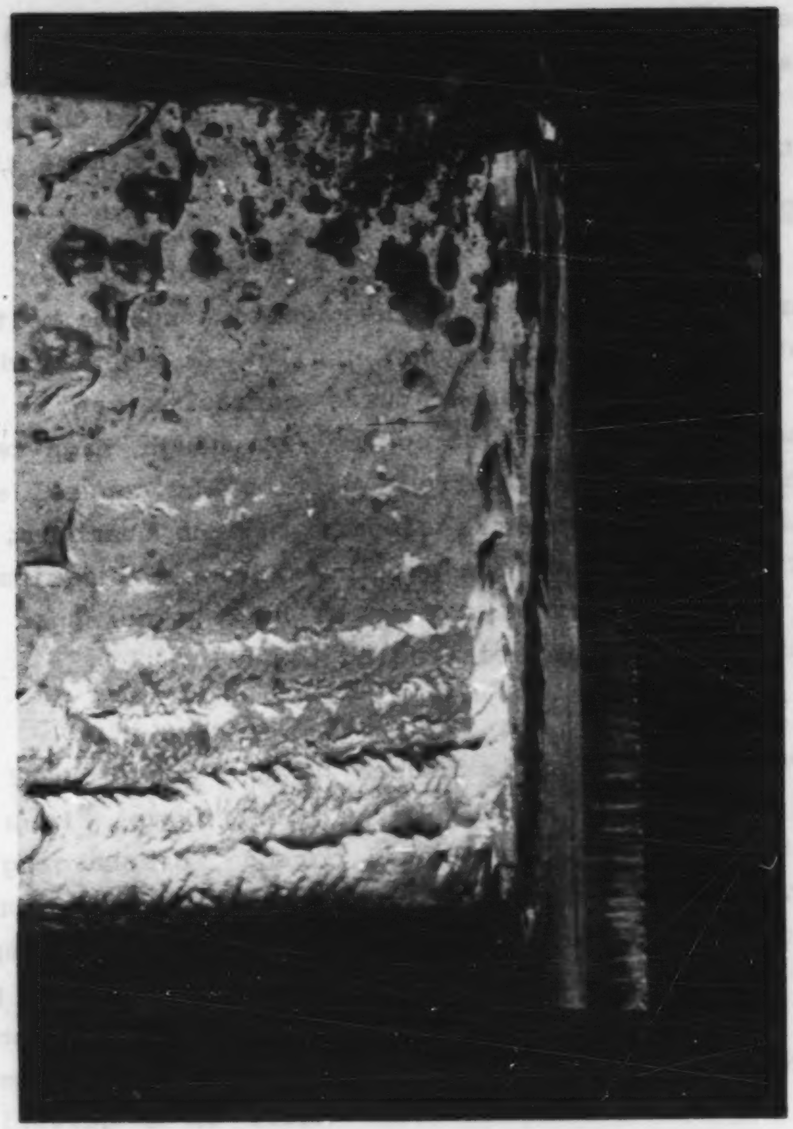

Figure 10. Scouring and erosion of a fan blade of an induced-draft fan serving an industrial boiler fabric filter.

OTHER MODES OF CORROSION

Other modes of corrosion include high-temperature corrosion and galvanic corrosion. Although these modes do not affect particulate control equipment as frequently as the three just discussed, they can become significant problems in some situations.

High-Temperature Corrosion

At temperatures over 325°C the importance of water in corrosion is overshadowed by other agents, such as molten salts, lead, vanadium, sodium, oxygen, sulfur dioxide, and hydrogen sulfide. At elevated temperatures corrosion can be extremely rapid and sometimes catastrophic. Although high-temperature corrosion does not often affect particulate control equipment, it can affect hot ductwork, dampers, quench chambers, and heat exchangers upstream from the particulate control equipment. The Source 6 report describes a case of high-temperature corrosion in the ductwork and dampers leading to an ESP.

Galvanic Corrosion

Galvanic corrosion is caused by the coupling of electrochemically dissimilar metals in an electrolyte. In a galvanic couple, the more anodic metal will corrode, discharging positive metal ions into the surrounding electrolytic solution. These ions typically combine with dissolved oxygen or ionic species in solution, such as hydroxyl ions, to form corrosion products. Electrons from the anodic metal are transmitted through the couple to the cathode where they participate in the various cathodic reactions. The cathodic metal in a galvanic couple generally does not corrode while the anodic metal tends to corrode at a faster rate than it would if not part of the couple. Table 1 contains a list of several common metals arranged according to their galvanic activity in seawater. The farther apart two metals lie in the galvanic series, the more severe will be the corrosion of the anodic metal. Common galvanic couples which result in corrosion include (the anodic or corroding metal is listed first) mild steel/stainless steel, mild steel/copper, aluminum/copper, aluminum/mild steel, and aluminun/stainless steel. These couples can sometimes be inadvertently constructed in piping systems with their many valves and fittings, and in mechanically fastened metal parts such as bolted joints, riveted joints, and access hatch hardware.

TABLE 1. GALVANIC SERIES OF SOME COMMON METALS IN SEAWATER[8]

Active or anodic	Magnesium alloys
	Zinc
	Aluminum
	Mild steel
↑	Cast iron
	Lead
	Tin
	Muntz metal
	Manganese bronze
	Naval brass
	Admiralty brass
	Copper
	Nickel
	76 Ni-16Cr-7 Fe
↓	Type 410 stainless steel (passive)
	Titanium
	Type 304 stainless steel (passive)
	Silver
	Gold
Noble or cathodic	Platinum

Note: The order of various metals in the galvanic series may be different in media other than seawater.

SECTION 4

FACTORS THAT CONTRIBUTE TO CORROSION IN CONTROL EQUIPMENT

Many factors contribute to the formation of corrosive conditions in particulate control equipment. If corrosion is to be prevented, it is important to recognize these factors and to understand how they are interrelated. The first part of this section is a discussion of factors which are inherent in the process being controlled, and the second part is a discussion of factors which vary according to operation and maintenance practices at a plant.

PROCESS CHARACTERISTICS

Many of the factors that determine the corrosivity of the environment affecting a particulate control device are a function of the process being controlled. Of prime importance is the chemical nature of the service environment. Also important are the temperature and moisture content of the flue gases, the operating schedule of the controlled process, and any process changes that are made after particulate control equipment is installed.

Chemical Constituents

Corrosive chemicals can enter the particulate control system from several sources including the process raw materials, the process fuels, combustion and dilution air, quench waters, and scrubbing waters. Although some of these constituents may be noncorrosive in their original forms or concentrations, they can be altered chemically or concentrated by various industrial processes. Some chemicals that are noncorrosive by themselves may have synergistic corrosion effects with other chemicals.

The two most common corrosives that affect particulate control equipment are sulfuric acid and chlorides. Sulfuric acid is a contributing factor in most corrosion problems affecting fabric filters and electrostatic precipitators. Observations made during the field inspections of this study and verified by the scrubber manufacturers interviewed, indicate that chlorides are responsible for the majority of corrosion problems in scrubber applications. Chlorides in combination with acidic scrubbing waters are especially troublesome.

Raw Materials-

Process raw materials are a primary source of corrosive contaminants in particulate-laden gases entering particulate control devices. Ores, clays, sands, aggregates, recycled scrap metals, plastics, slags, and other raw materials may contain a variety of corrosive secondary components in addition to their primary, economically valued components. For example, many ores (e.g., copper and iron) contain high percentages of sulfur, some of which can be oxidized to sulfur trioxide during refining processes. Crushed aggregates used in asphalt production, especially those mined in coastal areas, sometimes contain chlorides.

Recycled scrap metals used in secondary metals industries can contain a variety of corrosive contaminants. Feedstocks for secondary lead furnaces consist predominantly of lead-acid batteries, which contain sulfuric acid and chloride-bearing plastics. Feedstocks for the secondary aluminum and secondary copper industries can contain chlorinated rubbers and plastics. Feedstocks for cast iron cupolas typically contain a large percentage of internal combustion engine parts, which contain oil, lead, and paint residues. These generate a variety of flue gas contaminants.

Steel mill slags, which are sometimes used as raw materials for rockwool insulation cupolas, crushed aggregate dryers, and other processes, can contain sulfur. Finally, clays used in brick production, phosphate used in fertilizer production, and feldspar used in glass production often contain fluorides.

Fuels--

Fossil fuels, especially coal, metallurgical coke, and residual fuel oils, contain significant quantities of sulfur which can oxidize to sulfur trioxide during combustion. When such fuels are used in a process controlled by a dry particulate collection device, acid dewpoint corrosion may occur. In installations where wet scrubbers are used to control processes using fossil fuels, it is common for acidic conditions to develop in the scrubbing liquors.

Some fuels can introduce corrosive contaminants other than sulfur into the particulate control device. Polyvinyl chloride plastics and chlorinated rubbers, commonly burned in municipal incinerators and in wire burning incinerators, can generate hydrochloric acid. Some coals are an overlooked source of chlorides, in addition to being a source of sulfur.[9]

Scrubbing Liquors--

Scrubbing liquors can be a source of corrosive contaminants as well as a medium in which contaminants from flue gases can collect. Recycled scrubbing waters can be especially troublesome because recycling can increase the concentrations of corrosive contaminants by several orders of magnitude. Chlorides, acids, and other electrolytic species found in benign concentrations in the feed water or the flue gases can become quite corrosive as a result of the concentrating effects of recycling.

Flue Gas Temperatures and Moisture Content

Flue gas temperatures can have a great effect on corrosion and other forms of materials degradation in particulate control devices. Extremely high temperatures in combination with corrosive contaminants can result in high-temperature corrosion in ductwork and other components. High temperatures can also damage fabric filter bags, protective coatings and linings, and fiberglass-reinforced plastic components.

Gas temperatures can be reduced by dilution air dampers, quench chambers, radiant cooling loops, or heat exchangers. Reducing gas temperatures, however, can set the stage for acid condensation. Therefore, when hot flue gases are to be cooled, it is important to determine their moisture and sulfur trioxide contents so that the sulfuric acid dewpoint can be estimated. All possible sources of flue gas water vapor should be considered, including the water vapor added with dilution air or evaporative cooling and that which forms as a byproduct of fossil fuel combustion. If analysis indicates that temperatures will fall below the acid dewpoint it is advisable to reduce the amounts of water vapor and/or sulfur in the flue gases or to select an alternative particulate control strategy.

Process Operating Cycles

The operating cycles of a controlled process can sometimes influence the corrosion activity in a particulate control device. Operating cycles can affect dewpoint corrosion, because of the close relationship between process variations to variations in flue gas temperatures. In general, the more frequently a hot process starts up and shuts down or varies between full production and partial production, the more frequently the flue gases in the control device will pass through the acid dewpoint.

A number of operating cycles are possible in industrial processes, and they produce a variety of flue gas temperature cycles. At one extreme is the characteristic cycle of a cast iron cupola, which typically operates for melts lasting less than 24 hours between startup and shutdown. While a cupola melt is in progress, there are frequent charges of fuel, scrap iron, and fluxing; periodic blasts of combustion air through the tuyeres; and frequent iron and slag taps. Each of these operations effects the temperature of the cupola flue gases. Wide fluctuations in cupola flue gas temperatures can be tempered by gas cooling devices such as dilution air dampers, quench chambers, and heat exchangers. It is usually difficult with these devices, however, to maintain sufficient control of flue gas temperature to simultaneously protect the particulate control equipment from high temperature stresses and acid dewpoint corrosion. At most cupola installations, high temperature protection has priority over dewpoint control because a single high-temperature excursion can do immediate damage whereas dewpoint corrosion is a cumulative problem.

The other extreme in operating cycles is represented by the base-loaded utility boiler or a fully operational cement kiln which run for months at a time near their maximum firing rates. Industrial boilers fall somewhere between the two extremes in operation. These usually operate for periods lasting 5 to 6 days in length and can vary considerably in their firing rates at various times during a day.

Operating cycles can affect more than flue gas temperatures in some processes. For example, in iron and steel processes such as an oil-fired open hearth furnace (Source 8), the addition of lime fluxing can add a temporary burst of alkaline particulate to the flue gases that can raise the pH of scrubbing liquors. During periods between lime additions, sulfur oxides from the fuel combustion can lower scrubber pH drastically. These fluctuations in flue gas composition must be considered when designing a scrubber liquor pH control system. Similarly, the variability of refuse entering a municipal incinerator can affect the corrosivity of the flue gases. Residential refuse charged to an incinerator after a rainy period is likely to produce flue gases with a higher moisture content. Charging an incinerator with refuse that contains high percentages of polyvinyl chloride plastic is likely to produce flue gases with higher levels of hydrochloric acid.

The significance of the operating cycle of a process must be considered when developing a corrosion control strategy for particulate control equipment. Variability in flue gas temperatures and chemical constituents may be a determining factor in the type of cooling device chosen, the sophistication required

in a scrubber pH control system, or the type of particulate control device selected.

OPERATION AND MAINTENANCE PRACTICES

Operation and maintenance practices often affect corrosion in particulate control equipment. Operating parameters that influence corrosion are the control of flue gas temperatures, the variability of raw materials and fuels, the frequency of pH adjustments to scrubbing liquors, and scrubbing liquor blowdown and makeup rates.

In attempting to control the sulfuric acid dewpoint, it is often advisable to preheat a cold fabric filter or electrostatic precipitator before introducing moist, sulfur-bearing flue gases.[10] For processes having wide fluctuations in temperatures, it is advisable to vary the amount of dilution air or quench spray to match the changing temperatures, rather than presetting the amount of cooling for the highest expected temperature. Automatic cooling controls are preferable to manual controls. In processes such as cement kilns or hot-mix asphalt dryers, operators must avoid the temptation to lower process exhaust temperatures to save fuel unless they have also considered the effects that lower temperatures may have on dewpoint corrosion.

Changes in raw materials sometimes alter corrosion activity in a particulate control device. For example, a change in fuel from distillate oil to residual oil or coal can increase the sulfur levels in the gases. A change in the source of coal can change the amounts of sulfur and chlorides introduced into the system. Some clays used in brick and refractory production contain significant quantities of fluorides, whereas others do not. Likewise, some aggregates used in hot mix asphalt production contain high levels of chlorides while most do not. Finally, refuse containing high levels of plastics and chlorinated rubber will produce hydrochloric acid when burned in a municipal

incinerator, whereas refuse mixtures without these materials will not.

Management of scrubbing waters is also important for control of corrosion activity. In some scrubber systems pH control is critical. Continuous pH control is usually superior to periodic adjustments, but it requires good pH instrumentation and frequent operator monitoring. One scrubber manufacturer interviewed during this study reported that as many as 50 percent of the pH control systems for particulate scrubbers are not used at all because of the attention they require from the operators. The potential impact of an increase in the liquor recycle rate is also an important consideration. Increasing recycle rates increases the concentrations of acids, and other corrosive constituents.

Maintenance practices that can affect corrosion activity in particulate control equipment include the frequency at which various components are inspected and the speed at which malfunctioning components are repaired. Among the items which should be inspected frequently are pH control instrumentation (especially the pH probes), temperature control instrumentation, hatches, hoppers, fans and fan vibration sleeves, insulation, and mist eliminators.

SECTION 5

AVOIDING CORROSION IN CONTROL EQUIPMENT

Corrosion in particulate control equipment can be addressed in most applications through careful design and through the use of proper operation and maintenance procedures in both the control equipment and the controlled process. This section describes the most important of these tools for avoiding control equipment corrosion.

CONTROLLING ACID DEWPOINT CORROSION

Most of the manufacturers interviewed during this study agreed that acid dewpoint corrosion can be adequately controlled in nearly all fabric filter and electrostatic precipitator applications. The principal tools available for controlling acid dewpoint corrosion are reduction of sulfur trioxide and moisture levels in the flue gases, control of exhaust gas temperatures, use of proper thermal insulation, and prevention of cool air inleakage into the control device. In some cases the use of protective coatings and special alloys can be helpful; however, the cost of the latter is usually prohibitive for the major structural components of fabric filters and electrostatic precipitators.

Reduction of Sulfur Trioxide and Moisture Levels

Assuming that there is no moisture inleakage into a control device, the levels of sulfur trioxide and moisture in the flue gases are dependent on process characteristics. The best way to keep the sulfuric acid dewpoint temperature low is to select fuels with as low a sulfur content as possible and to select dry-type flue gas cooling systems whenever possible.

It should be noted that the use of low sulfur fuels is no panacea for acid dewpoint corrosion, however. Low sulfur coals and residual oils can generate sufficient sulfur oxides when burned to cause acid dewpoint corrosion; the use of these fuels merely lowers the dewpoint temperature which makes acid condensation easier to prevent. Economics usually governs the ultimate decision on the type of fuel to be used. Any cost analysis of available fuel options should consider the possible costs of corrosion damage to the particulate control equipment and lost production following corrosion failures as well as the relative costs of the fuels.

The types of systems available for cooling flue gases are evaporative cooling (i.e., quench chambers), dilution air, and heat exchangers. Evaporative cooling injects considerable moisture into the flue gases. Dilution air cooling also can introduce moisture into flue gas streams, depending on the relative humidity of the ambient air. From the standpoint of corrosion, heat exchangers are the preferred cooling method because they add no moisture to the flue gases. As with fuel, economics plays a major role in the selection of a flue gas cooling system. Dilution air systems usually entail the lowest capital investment, whereas heat exchangers usually entail the largest capital investment. Part of the costs of heat exchanger systems often can be recovered by reuse of the waste heat removed. Recuperative heat exchangers can be used to preheat combustion air or for other energy conservation purposes. Installed costs of evaporative cooling systems usually fall somewhere between those of dilution air systems and heat exchanger systems; however, they also require a supply of water.

Control of Flue Gas Temperatures

Flue gas temperatures are a function of the process characteristics and of the flue gas cooling systems. Processes such as cast iron production are not ammenable to flue gas temperature control at the process. Sources such as these require the use of flue gas cooling devices. Primitive systems such as a manually operated dilution air damper are usually not sufficient to insure that flue gases remain above the dewpoint. Control devices with temperature sensors to automatically control dilution air are preferable. Evaporative cooling is not recommended for cast iron cupolas, but recuperative heat exchangers have been used successfully.

In processes such as cement kilns, where operating conditions are relatively stable, it is sometimes possible to control exhaust temperatures by adjusting the firing rates and the amounts of excess combustion air. In such processes, it is helpful to have temperature sensors in the control device which can automatically control the process firing rates or sound alarms in the plant's control room whenever temperatures in the control device fall below a safe level. The increase in fuel consumption required to maintain high kiln exhaust temperatures must be weighed against the savings attributable to reduced corrosion in the particulate control system.

Another important means of controlling acid dewpoint corrosion is to preheat the control device prior to the introduction of corrosive flue gases.[10] For example, a rotary dryer can be preheated by firing the burner at a reduced rate for a period of time before introducing the wet aggregate. A cupola can be preheated by firing natural gas afterburners for a period of time prior to lighting the sulfur-bearing coke charge. The advantage of preheating is that the hot corrosive flue gases will not contact cold steel surfaces in the control device during startup as would occur without preheating. As in the case of other flue gas temperature control measures, the advantage of preheating must be weighed against the additional fuel expenses.

Thermal Insulation

Thermal insulation is another means of maintaining flue gas temperatures above the acid dewpoint. The ultimate purpose of insulation is to reduce the amount of flue gas cooling that takes place between the time the gases enter the ducting to the control device and the time they exit the stack. At some installations, insulation alone will solve acid dewpoint corrosion problems; in others it is only a supplementary measure.

Insulation will be most effective if a few simple guidelines are followed.[11] Any insulation must be thick enough to sufficiently impede the flow of heat through the external surfaces of the control device. The insulation must also cover all exposed surfaces including the dust hoppers, access doors, and the ductwork. The insulation must be installed in such a manner that it will remain intact over the life of the equipment. Most types of insulation should have a protective sheath (usually sheet metal) on the outside to repell rainwater and to prevent mechanical damage. An insulation blanket should be sealed at the top and bottom to prevent a "chimney effect" circulation of outside air through or underneath the blanket. An example of a properly insulated electrostatic precipitator is shown in Figure 11.

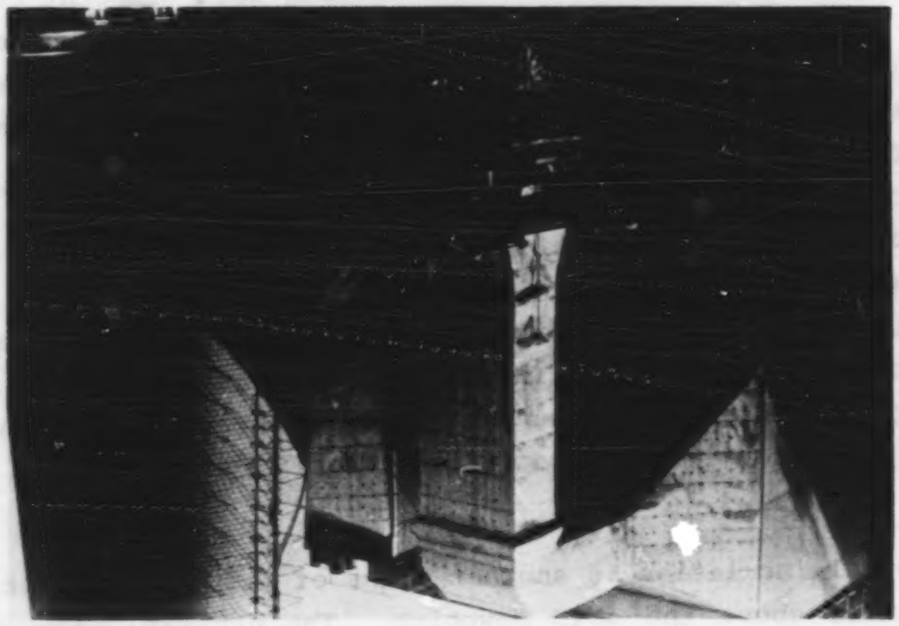

Figure 11. Electrostatic precipitator with a complete blanket of insulation covering the chambers, hoppers, and ductwork.

Among the common errors made in insulating control equipment are the failure to insulate all exposed ductwork (including reverse air ductwork for the cleaning of fabric filter bags), the failure to insulate hatches, and the failure to attach the insulation securely. Another common error (Figure 12) is to allow structural members to protrude through the blanket of insulation; these members radiate heat away from interior surfaces of the control device and promote condensation at these locations. Figure 13 shows improper sheathing of the insulation surrounding a duct. The gap in the sheathing can channel rainwater into the insulation and cause the exterior surface of the duct to remain moist.

Air Inleakage

Unexpected air inleakage can spoil a well-designed acid dewpoint control program in a fabric filter or an electrostatic precipitator. Inleakage allows not only moisture from the ambient air to enter the control system, but also causes severe localized cooling at the point of entry. Both phenomena can contribute to acid dewpoint corrosion. Inleakage is a self-feeding process--the metal adjacent to the initial penetration tends to corrode at an accelerated rate, which promotes enlargement of the penetration. Inleakage is common in poorly fitting hatches (Figure 5), hatches with worn seal gaskets, rotary air locks with worn seals, cracked vibration sleeves (Figure 14), and incomplete welds. It can also occur in ductwork or at the process. Inleakage should be repaired promptly to avoid further damage.

Special Alloys and Protective Coatings

The relatively large size of most fabric filters and electrostatic precipitators makes it uneconomical to use higher priced stainless steels or nickel alloys as the principal materials of construction. Most structural components of these devices are constructed of carbon steel or, in some cases, Corten or cement block. Special alloys are used, however, for some

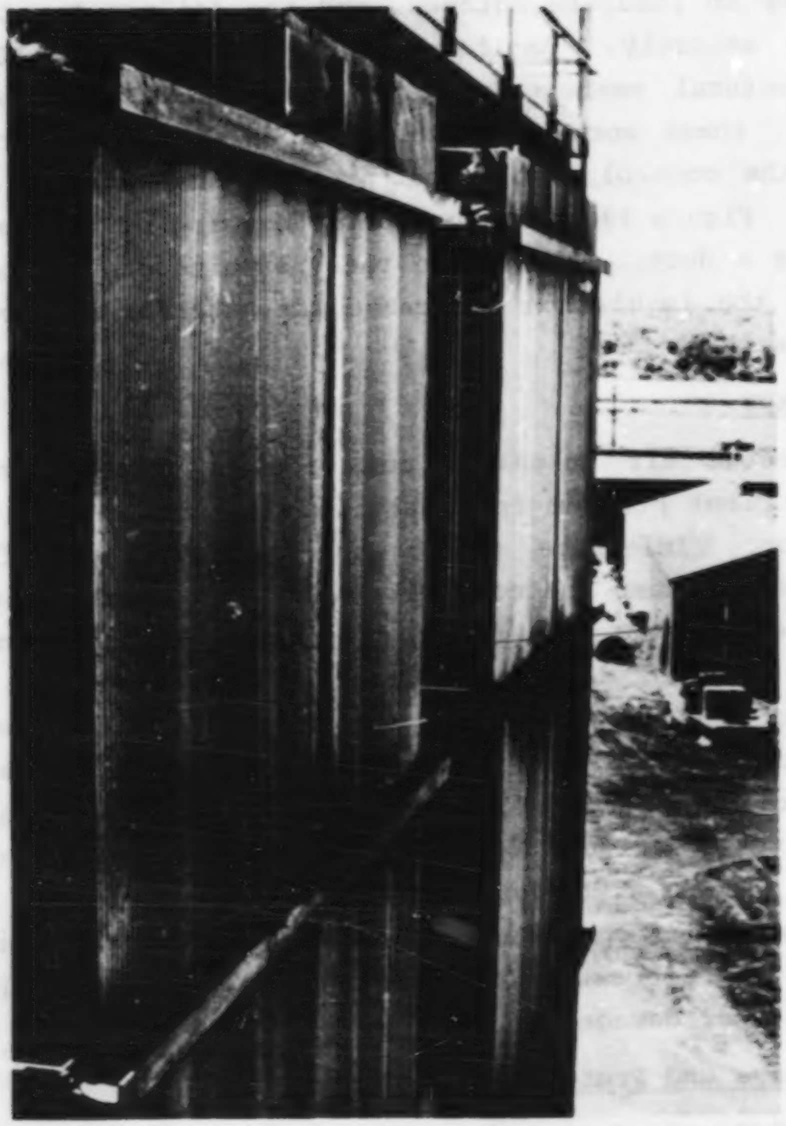

Figure 12. Insulated fabric filter with structural steel protruding through the insulation.

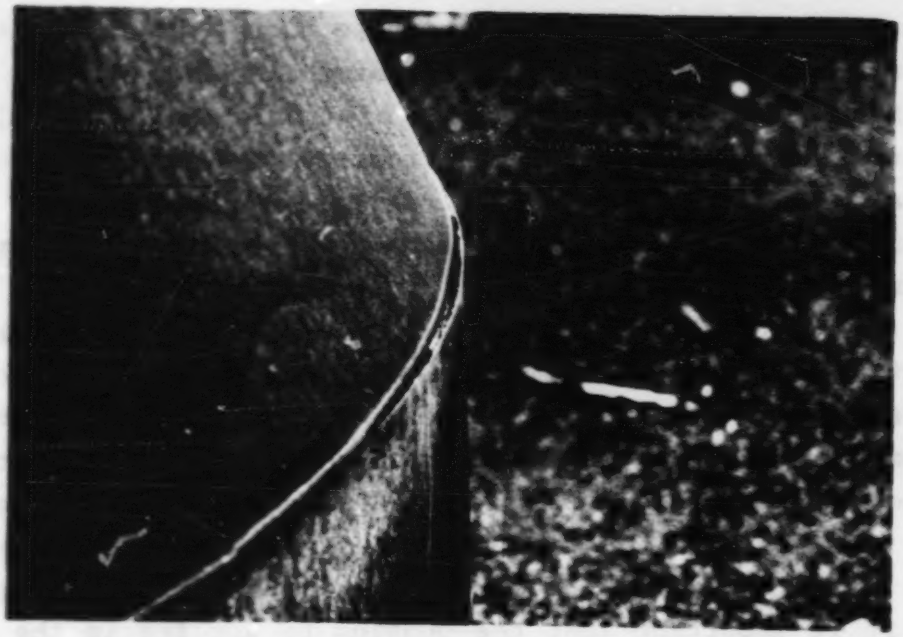

Figure 13. Gap in the sheathing covering an insulated duct.

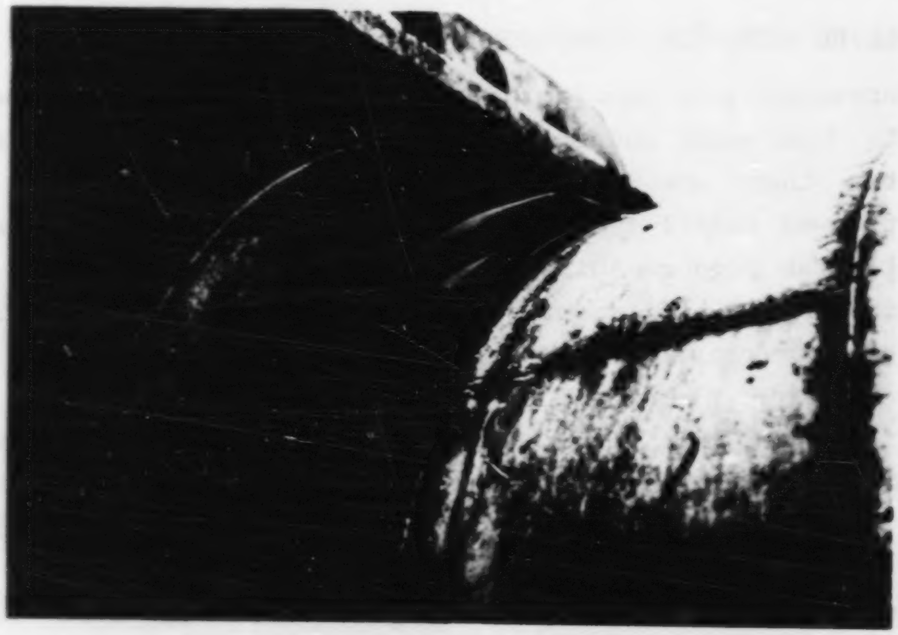

Figure 14. Cracked vibration sleeve in ductwork, which allows air inleakage into the system.

of the smaller components within these ducts, such as filter bag hardware and electrostatic precipitator discharge wires.

Nearly all exterior surfaces of fabric filter and electrostatic precipitator enclosures receive a protective coating. However, the interior surfaces of these devices are not always coated. One fabric filter manufacturer reported that only 10 percent of its filters receive internal coatings. The reason that coatings are not often used is that few seem to be very effective on hot sources. Despite claims of some coatings manufacturers, long-term performance of most available coatings systems is not good in hot corrosive flue gases. All control device manufacturers interviewed reported that most coatings fail when exposed for prolonged periods to acid bearing flue gases above 300 to 400°F. In cases where a coating is appropriate, it is important that the coating be applied in the proper manner to a properly prepared surface. In most cases, this requires that the coating be applied in the shop rather than in the field.

CONTROLLING SCRUBBER CORROSION

Corrosion problems arise frequently in scrubbers because exhausts from many industrial processes contain gases and particulates that are corrosive when dissolved in water. The combustion of fossil fuels such as coal, metallurgical coke, and fuel oils can produce sulfuric acid in scrubbing liquors. Coals can also contain sufficient chlorides to cause scrubbing liquors to become corrosive to many alloy steels.[9] Combustion of polyvinyl chloride plastics, commonly found in incinerator feedstock, also yields chlorides. Rotary aggregate dryers can contribute chloride- and fluoride-bearing particulate to exhausts. Fluoride-bearing particulate is especially troublesome in the phosphate fertilizer and the feldspar industries.

Prevention of corrosion in scrubbers is best handled through proper choice of materials and through scrubbing liquor pH control. Recirculation of scrubbing liquors greatly increases the concentrations of any corrosive agents they contain. Reduction or elimination of liquor blowdown can increase the concentrations of corrosive constituents in the liquor that otherwise acceptable materials of construction may become susceptible to corrosion.

Selection of Materials for Scrubbers

Materials of construction for scrubber applications must be carefully selected to withstand corrosive and abrasive agents in the gases and liquors and any high temperatures that are likely to occur. Most manufacturers interviewed contended that if the process conditions are properly defined before design begins, the experienced scrubber manufacturer can design a scrubber that will withstand its service environment. Many scrubbers fail because inappropriate materials are selected after a superficial investigation of process conditions, or because less resistant materials are substituted to reduce costs.

Investigation of each scrubber application should include chemical analysis of the raw materials, combustion products, and scrubbing liquids and a review of the operating histories of scrubber installations in similar applications. Finally, review of literature about materials performance is recommended, and when materials performance data are not available, in situ coupon tests may be required. After all relevant information has been compiled, the designer should prepare a list of materials suitable for the expected service. Selection of materials of construction from this list will be based in part on their relative costs.

Although the above-mentioned procedures should always be followed in the selection of materials, some general aspects of materials applications can be summarized here. Table 2 lists the major categories of materials available for scrubbers and ancilliary components, together with their major properties, general corrosion behavior, and relative costs.

TABLE 2. PROPERTIES OF MATERIALS USED IN THE CONSTRUCTION OF WET SCRUBBERS AND AUXILIARY COMPONENTS[7,8,12]

Material	Properties	Corrosion resistance	Uses
Cast iron	High strength; low ductility; brittle; hard; low cost	Gray or white cast irons exhibit fair resistance to mildly corrosive environments; high-silicon cast irons exhibit excellent resistance in a variety of environments (hydroflouric acid is an important exception); cast irons are susceptible to galvanic corrosion when coupled to copper alloys, stainless steels	Pump casings, valve casings, piping; often used with linings in corrosive service
Carbon steel	Good strength, ductility, and workability; low cost	Fair to poor in many environments; low pH and/or high dissolved solids in moist or immersion service leads to corrosion; properly applied protective coatings give appropriate protection in many applications; susceptible to galvanic corrosion when coupled to copper alloys, stainless steels	General purpose in noncorrosive environments
Martensitic stainless steels (410, 416, 420, 440)	Iron-chromium alloy, hardenable by heat treatment; costs 2 to 5 times more than carbon steel	Good	Typically used for machine parts; rarely used in scrubber applications
Ferritic stainless steels (405, 430, 442, 446)	Iron-chromium alloy, not hardenable by heat treatment; costs 2 to 4 times more than carbon steel	Good; better than martensitic stainless steels; resists stress corrosion caused by chlorides; better chloride resistance than austenitic stainless steels; susceptible to crevice corrosion and pitting	General purpose; certain alloys good for high-temperature service; not as commonly used in scrubber applications as austenitic stainless steels
Austenitic stainless steels (201, 202, 301, 302, 304, 310, 316, 317, alloy 20)	Iron-chromium-nickel alloy; not hardenable by heat; hardenable by cold working; nonmagnetic; cost 3 to 10 times more than carbon steel; alloys with "L" designation (e.g., 316L) have lower carbon content for improved weldability	Good in oxidizing environments; fair in nonoxidizing environments; susceptible to pitting and stress corrosion cracking in chloride solutions. Type 310 resists high temperature corrosion; types 316 and 317 contain molybdenum for better chloride and pitting resistance; alloy 20 has excellent resistance in many environments	Scrubber vessels; fans; stacks and ductwork; mist eliminators; quench chambers

(continued)

Table 2 (continued)

Material	Properties	Corrosion resistance	Uses
Nickel alloys (Inconel,[a] Incoloy,[a] Monel,[a] Hastalloys,[b] Chlorimet,[c] and others)	Good strength; costs more than 10 times as much as carbon steel; also expensive to fabricate; commonly alloyed with chromium, iron, or copper	Excellent resistance in most environments; not resistant in strong oxidizing solutions such as ammonium and HNO_2; most have good resistance to stress corrosion; some nickel-copper alloys have good resistance to hydrofluoric acid	Scrubber vessels, fans; stacks and ductwork; mist eliminators
Titanium	High strength; light weight (60% that of steel); costs at least 10 times more than carbon steel	Exceptional resistance at ambient temperatures; excellent resistance at other temperatures, except that crevice corrosion is possible in chloride solutions above 250°F	Not widely used in scrubber service because of costs; sometimes used in severe environments in fans and other components
Aluminun alloys	Good strength-to-weight ratio; good electrical and thermal conductivity	Good atmospheric corrosion resistance (except in salt mist exposure for certain alloys); some alloys suitable for immersion in certain acids; susceptible to galvanic corrosion when coupled to most other metals	Not widely used in scrubber service
Fiberglass-reinforced plastics (FRP)	Good chemical resistance; poor abrasion resistance; cannot be used in high-temperature service; low hardness	Excellent in many corrosive environments; actual results depend on type of plastic resin used	Scrubber vessels, piping, mist eliminators, ductwork and stacks
Wood	High tensile and shear strength perpendicular to grain; low tensile and shear strength parallel to grain; low hardness; poor abrasion resistance; cannot be used for high-temperature service	Good resistance in dilute acids (including hydrofluoric acid); susceptible to biological attack under certain conditions; deteriorates in alkaline solutions	Scrubber vessels, tanks, especially in fluoride exposure; fir and cypress are popular species

[a] Registered trademark of Huntington Alloys, Inc.

[b] Registered trademark of the Stellite Division of the Cabot Corporation

[c] Registered trademark of the Duriron Company, Inc.

The success of protective coatings and linings in scrubber applications has been variable. Several manufacturers reported successful use of linings in certain applications, including the use of rubber linings in coal-fired utility boiler scrubbers and flaked-glass linings in hot ductwork. Rubber linings are also common in scrubber liquor pumps. Other protective coatings used in some scrubber applications include various epoxies and fiberglass reinforced plastics (FRP's).

Difficulty of application and repair are inherent problems in the use of coatings and linings. Proper application of coatings and liners requires a well prepared metal substrate and good application techniques. A poor anchor pattern after sandblasting or the presence of oil, dirt, or condensed water on the surface can cause a coating to disbond. Improper formulation or mixing of a coating in the liquid state, the inclusion of air bubbles during application, or improper curing after application can also cause coating failure. Finally, coatings are susceptible to mechanical damage and repair of improperly applied or damaged coatings is usually difficult. One vendor interviewed prefers to select resistant materials of construction rather than to resort to coatings and linings. The same manufacturer indicated that solid FRP presents fewer problems than FRP-lined steel.

Control of Scrubber Liquor pH

The neutralization of extremely acidic scrubbing liquors can often reduce the need for expensive materials of construction in scrubbers. For example, mild steels which fail when exposed to low pH solutions are less likely to fail in neutral solutions. Likewise, many forms of chloride attack in stainless steels occur only under low pH conditions. Control of pH, therefore, can substantially reduce the costs of materials in scrubbers and lengthen the useful life of many components.

Systems for the control of pH have not always proved to be reliable, however. Most scrubber manufacturers admitted that the majority of scrubber pH control systems do not perform adequately. In most cases the problems are a lack of technical expertise on the part of the operators and a lack of regular maintenance. In some installations delivered pH control systems are not used because the operators are unable or unwilling to perform the required maintenance. One scrubber manufacturer insisted that the pH control systems can work if properly designed and reported that some systems have operated for as long as six months without calibration. In contrast, other pH control systems (see Sources 1 and 8, Appendix A) require calibration as often as once per shift and still do not provide entirely satisfactory service.

A pH control system that is to be the principal defense against corrosion will usually require maintenance at frequent intervals, especially at the pH electrodes. Maintaining clean, calibrated probes is often difficult, but calibrated probes are vital to the success of a pH control system. Ultrasonically cleaned probes usually provide greater reliability than ordinary probes. To assure a representative measurement, the pH probes must be located at carefully selected points in the system. Probes located in stagnant areas may provide unrepresentative data, whereas probes subjected to high turbulence or fouling conditions may require frequent replacement.[13] The required frequency of chemical addition to scrubbing liquors will depend on the variability of the flue gas acidity, the detention time of the liquor in the treatment and recirculation systems, and the type of chemicals used for pH adjustment. In highly variable processes such as open-hearth furnaces and cupolas, a large settling basin can help dampen sudden changes in liquor pH, as will the addition of chemicals with a high buffering capacity, such as lime.

Abrasion in Scrubbers

Abrasion can occur when gases or scrubbing liquors containing high concentrations of abrasive particulate are in the turbulent mode or are subjected to a sudden change in flow direction. Typical wear areas in scrubbing systems include venturi throats, walls of centrifugal mist collectors near the inlet duct (Figure 9), and elbows in the ductwork.[14] One manufacturer cited the wet-dry line in scrubbers serving hot sources as particularly susceptible to corrosion and abrasion. Solutions to abrasion wear include the use of precleaning devices and the use of large-radius turns in ductwork.

Rotating equipment such as fans, pumps, and clarifiers must receive special attention in scrubber service because of potential abrasion, plugging, and corrosion. Key wear areas in these components are the bearings and any components rotating in the fluid stream.[15]

Fan wear is a commom problem. Forced-draft fans often suffer abrasion because of exposure to particulate-laden gases. Wear in forced-draft fans can be reduced by use of special wear-resistant alloys, by reduction of fan rotation speeds (i.e., installing a larger fan), or by moving the fan to an induced-draft location on the clean-air side of the scrubber system. Blades of induced-draft fans can suffer corrosion or solids buildup if mist is carried over from the liquid entrainment separator. Induced-draft fan problems can be addressed by use of corrosion-resistant materials and by improving liquid entrainment separation.

Pump wear is also a common problem in scrubber systems. Pump housings, impellers, and seals are subject to abrasion and corrosion by scrubber slurries. The use of rubber linings and special alloy pump materials will reduce abrasion and corrosion of the housings or impellers, and installation of a water flush in the seals can help reduce wear of the seals.[15]

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APPENDIX A: CASE HISTORIES

INSPECTION REPORTS FOR EIGHTEEN PARTICULATE CONTROL SYSTEMS THAT HAVE EXPERIENCED CORROSION

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SOURCE 1

WET SCRUBBERS SERVING MUNICIPAL INCINERATOR

SUMMARY

This facility houses two identical incinerators for burning household and light industrial wastes. Each incinerator has a wet scrubber for controlling particulate matter emissions.

From startup, the air pollution control system has been subject to severe corrosion. All major equipment in the control system has now been replaced except for the scrubber vessels which are in a poor state of repair. Corrosion-related expenses are well in excess of $1 million.

One of the scrubbers has never achieved compliance with particulate matter emission standards, and the other only recently achieved compliance. Experiments are continuing in an attempt to find a modification in the first scrubber that will achieve compliance.

SOURCE DESCRIPTION

The source is a municipal incinerator that began operating in 1969. The plant operates 24 hours per day, 7 days per week, and 52 weeks per year.

The facility consists of two identical incinerators that each burn 270 Mg of refuse per day. The quality of the refuse is quite variable and dependent on seasonal effects (e.g., grass cuttings) and on the unpredictable nature of industrial disposals. In each incinerator, the waste is burned in a moving grate supplied with underfire air and followed by a rotary kiln. Trash such as paper and cardboard is used for starting the fire. Combustion efficiency is dependent on the quality of waste available because there are no facilities for additional firing of natural gas or oil.

The gases pass from the kiln to either a bypass stack or to the air pollution control system. Each air pollution control system consists of a quench chamber, followed by a spray scrubber, mist eliminator, wet fan, and stack. The gases exit from the stack at about 77°C.

The quench section is constructed from refractory-lined mild steel. The scrubber shell, spray nozzles, and 6.35-mm diameter mist eliminator support rods are constructed from 316L stainless steel. Experiments are continuing with different demister media; currently, Telerets and B-Gon polypropylene moldings are being evaluated. The fan impeller and housing are fabricated from Incoloy 825. The stack and the ductwork above the fan are constructed from fiberglass reinforced plastic (FRP).

Each scrubber treats 47.2 m^3/s of flue gases. This requires the use of 1140 ℓ/min of water in the quench section and 1920 ℓ/min of water in the spray vessel. Of this, about 380 ℓ/min are emitted through the stack as water vapor, and 190 ℓ/min are bled off to the lagoon. The rest of the water is recycled. Makeup water is monitored on only one scrubber.

Nine months after startup, pH control of the recycled water was instituted. The plant currently uses once a day grab sample analysis as the basis for estimating the amount of ammonia that must be added to maintain a pH of approximately seven.

Ash from the incinerators is landfilled, as is any material deemed to be noncombustible. A company is planning to recover metals from the ash.

MALFUNCTIONS DUE TO CORROSION

Problems occurred soon after startup of the system, and they have continued throughout the operating history of the plant.

Scrubber Pumps and Pipework

Within 6 months of startup, the black iron pipework failed due to general corrosion. The pipework was replaced with ceramic-lined mild steel. No further problems have been reported.

The housing and impellers of the recirculation pumps, which were constucted from Nihard, failed after a short time in service. The replacement pumps, which had rubber-lined impellers and housings, also failed after only a short service life. Duriron pumps were then installed, and these have worked well for 8 years.

Quench Chambers

The original quench chambers were constructed from Inconel 600. These failed after 6 years and were replaced with refractory-lined steel.

Scrubber Shells

The combined scrubber and mist eliminator shells are fabricated from 316L stainless steel. After 3 years, the shells began to corrode. After about 6 years, the inside of each shell was sandblasted. The upper portion was lined with FRP, and the lower portion was lined with castable concrete. The FRP was not successful and soon began to fail. Reportedly, chemical attack gave the FRP a burned appearance. The concrete also fell apart.

At the time of the inspection, the scrubber shells were suffering from severe pitting (Figure A1-1). Many pits had penetrated the scrubber shells allowing scrubbing liquor to flow down the outside of the shells and evaporate and leaving concentrated corrosive solutions and corrosive salt deposits on the external surfaces of the shells (Figures A1-2 and A1-3).

Because the corrosion appeared to be associated with the welds, improper welding techniques may be responsible for some of the failures. It was also apparent that some plates of the shell were attacked more severely than others (Figure A1-1), possibly because of the internal configuration of the scrubber (alignment of sprays or demisters, delamination of lining, etc.)

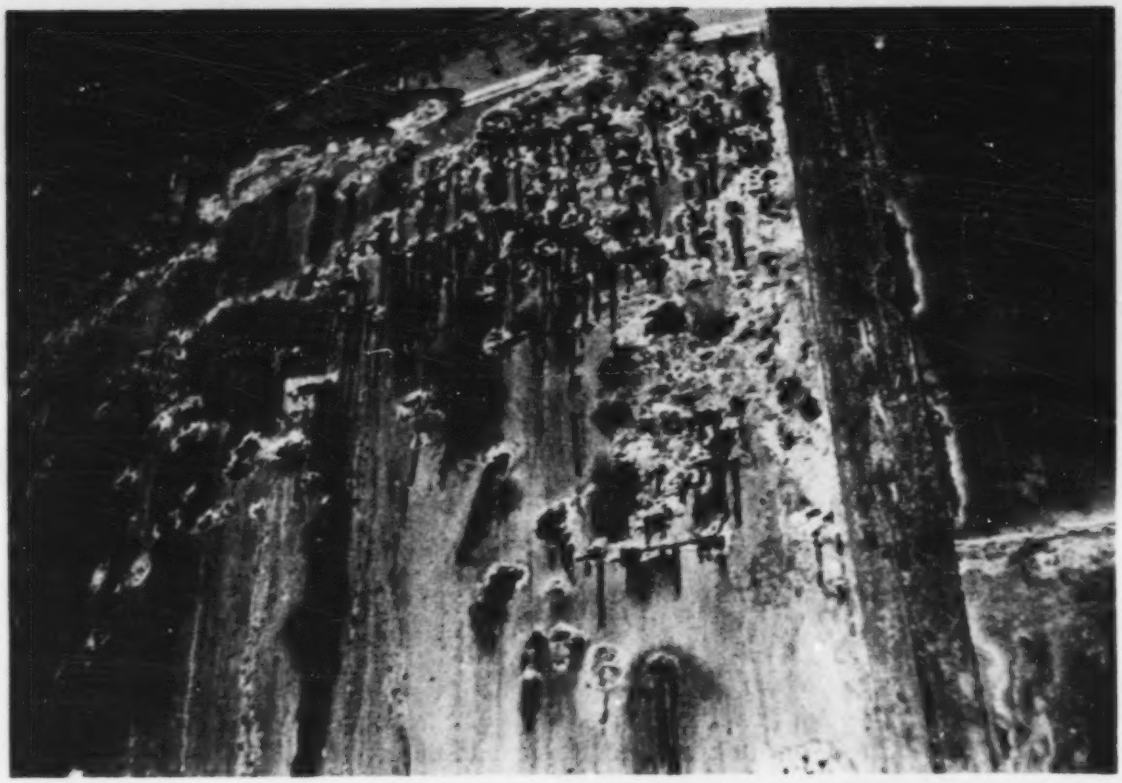

Figure A1-1. Severe pitting apparent on external surface of one of the scrubber vessels.

or because some of the plates were of a different grade of stainless steel than that specified.

Scrubber Internal Components

Continual problems have been experienced with the mist eliminators. Different materials and configurations have been used in attempts to meet emission standards. The original mist eliminators were constructed from stainless steel and lasted 1 month. The plant is currently using a 0.3-m layer of Telerets, followed by five layers of B-Gon polypropylene moldings supported by 6.35-mm diameter, 316L stainless steel rods.

Spray nozzles are constructed from 316L stainless steel and have a life of 6 to 7 years. Tests have been carried out with other materials, but none has proved to be more durable (e.g., brass spray nozzles lasted only 6 months).

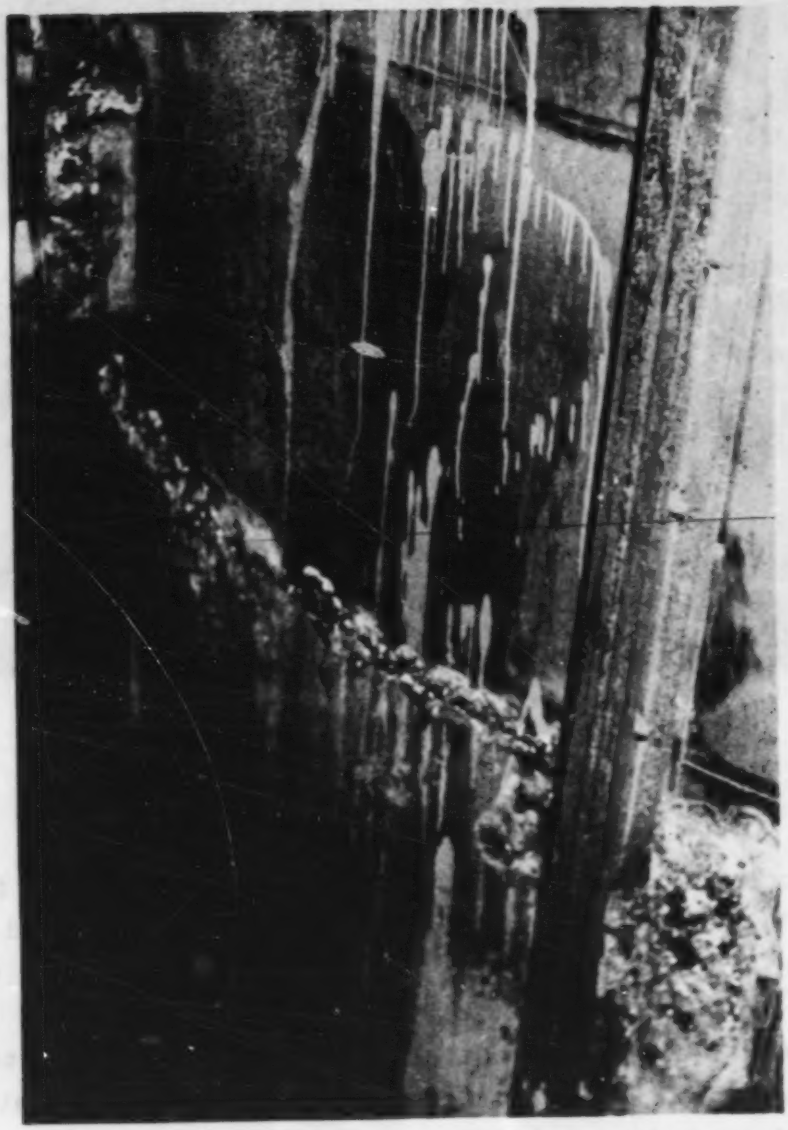

Figure A1-2. Salt deposits at corrosion leaks in the scrubber vessel. The corrosion appears to be structurally dependent, possibly affected by the internal configuration of the scrubber.

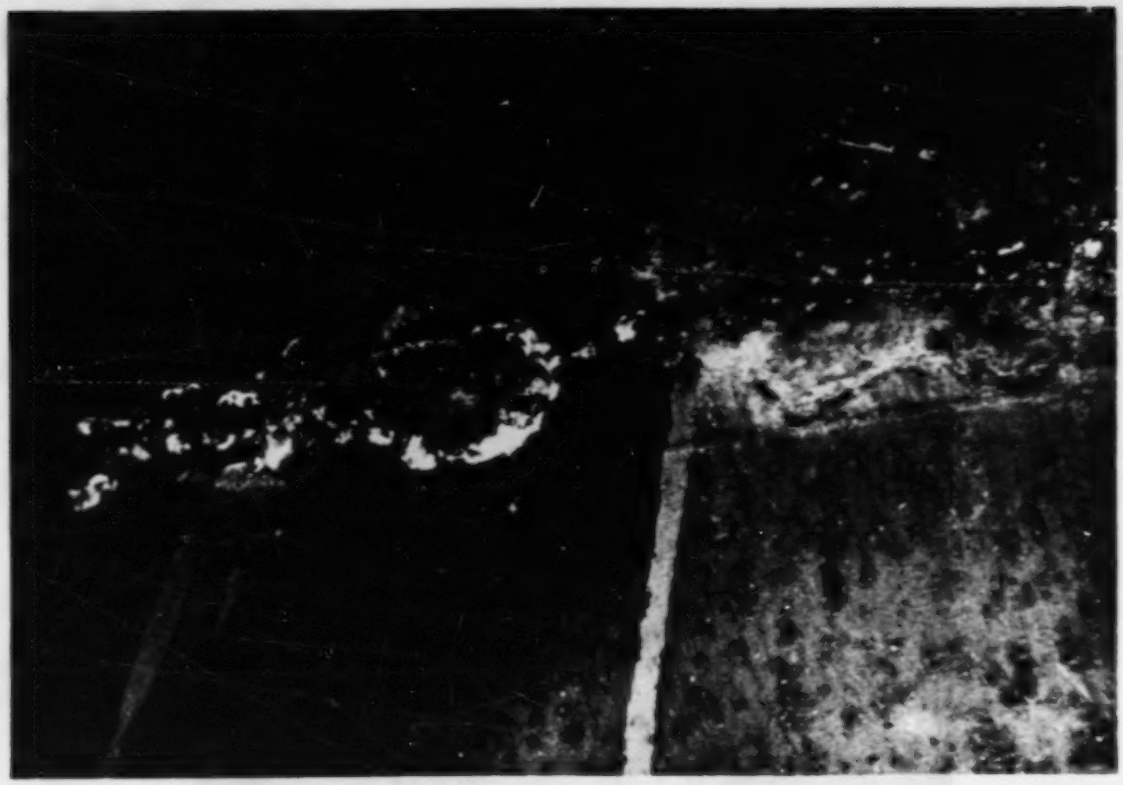

Figure A1-3. Salt deposits on the external surface of the scrubber vessel.

Fans

The original induced draft fans were constructed from mild steel that lasted about 3 years. They were replaced by fans constructed from Incoloy 825, which serve moderately well but are prone to stress corrosion cracking. The Incoloy fans are removed from service periodically and welded in an attempt to repair developing cracks. Occasionally, fans fail catastrophically and must be replaced. Once when this happened, a fan constructed from Carpenter 20 was installed because of the limited availability of fans constructed from Incoloy 825. The Carpenter 20 fan corroded and failed after 2 years.

Stacks

The original system was built with one stack for each incinerator. Consequently, each stack operated continuously, sometimes in the hot dry (bypass) mode and sometimes in the warm wet (scrubber) mode. The original stacks were fabricated from Inconel 600; these required patching during their 3-year life. In 1973, the original single stack on each incinerator was replaced with a dual stack system. A hot dry (bypass) stack was constructed from mild steel lined with refractory brick, and a warm wet (scrubber) stack was constructed from FRP. The stacks are currently holding up well, though there is some leakage at joints in the FRP stacks (Figure A1-4).

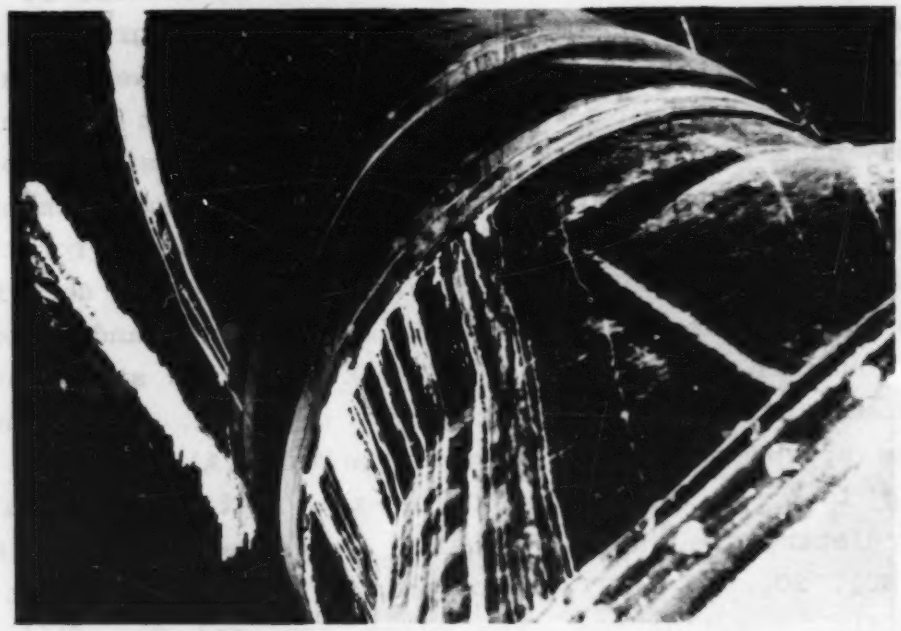

Figure A1-4. Leaks in fiberglass-reinforced plastic ductwork leading to the stack.

DESIGN EVALUATION

Materials of Construction

Wet scrubbers that control emissions from incinerators are subject to extremely corrosive gases and dusts. Therefore, rapid attack and failure of a scrubber vessel would be expected unless careful consideration had been given to the materials of construction. Recirculation of the scrubbing water also tends to accentuate corrosion because of the buildup of aggressive ions in the water. Incineration of household waste releases significant quantities of HCl from plastics (e.g., PVC) and other constituents. In acidic chloride environments, austenitic stainless steels (e.g., 304, 316) are prone to pitting and would not usually be expected to give satisfactory service. It is not surprising, therefore, that the scrubber vessel has suffered from severe localized corrosion. Additionally, the corrosion of the original pipework and the pumps should have been expected because of the highly acidic pH of the recirculating water.

This plant is particularly interesting because it was the subject of a scrubber materials evaluation program during the second year after startup.[1] Various alloys were evaluated. Specimens immersed in a channel carrying effluent scrubber water rapidly became coated with adherent deposits consisting of $PbSO_4$ and $CaSO_4 \cdot 2H_2O$ combined with barium, silicon, and aluminum compounds. Reportedly, these deposits afforded some protection to the samples. The behaviors of the specimens are described in Table A1-1. Generally, Ti-6Al-4V, Hastelloy C, and Inconel 625 were found to be superior. The 316L stainless steel was found to be susceptible to stress corrosion cracking. The composition of the scrubber effluent is given in Table A1-2. It is interesting to note the effects upon the salt concentrations of recirculating the water. The flue gases were believed to contain HCl, SO_2, SO_3, HF, and organic acids. As a result of the materials investigation, the plant replaced the failed mild steel fans with ones constructed from Incoloy 825; these have performed fairly well.

A second study was performed at a sister plant of similar design. The plant differed in that the scrubber was operated with zero blowdown, there was no pH control system, and the incinerators were fueled by a higher percentage industrial of wastes. These differences resulted in chloride levels of 30,000 ppm in the scrubbing liquor and pH values of about 2.5. This second study, however, came to conclusions similar to those of

TABLE A1-1. EVALUATION OF ALLOYS UNDER INCINERATOR SCRUBBER CONDITIONS

Alloy	Performance
Ti-6Al-4V	Good
Hastelloy C	Good
Inconel 625	Good
Hastelloy F	Good
Hastelloy C-276	Good
Hastelloy G	Good
Ti75A	Good
S-816	Good
Carpenter 20	Pitted
Incoloy 825	Pitted
316L	Pitted, Stress corrosion cracking
310	Pitted
446	Pitted
Inconel 600	Trenches
Inconel 601	Trenches
Armco 22-13-5	Pitted
USS 18-18-2	Pitted
304	Pitted, Stress corrosion cracking

TABLE A1-2. SCRUBBER WATER COMPOSITON DURING EXPOSURE PERIOD[1]

	Date			
	8/31/71	10/8/71	11/2/71	12/8/71[a]
Total hardness as $CaCO_3$, ppm	2330	2760	2760	272
Calcium as Ca, ppm	568	784	1704	71
Magnesium as Mg, ppm	262	230	573	27
Sulfate as SO_4, ppm	1261	1308	1933	231
Chloride as Cl, ppm	2355	2355	1610	183
Specific conductance mmho/cm	7499	7639	11,160	833
Total solids, ppm	5916	5900	11,386	732
Suspended solids, ppm	114	14	10	114
Total acidity as $CaCO_3$, ppm	402	388	352	68
pH	4.4	4.3	5.1	4.0

[a] On this date the scrubber water was not being recirculated.

the first study. The most satisfactory materials were found to be Hastelloy C-276 and Inconel 625, although it was reported that even these materials were likely to suffer localized corrosion in the low-pH, high-chloride environment (titanium products were not studied). Types 316 and 304 stainless steels were found to be unsatisfactory.[2]

Plant Design

Elements of the original design have helped to accentuate corrosion and consequent air pollution problems.

The use of a single stack for both bypass and scrubber modes gives particularly arduous service conditions for stack materials. No materials have been proven adequate for such service.

The lack of pH control for the recirculation water led to problems in piping and pumps, and probably initiated problems in the scrubber itself. The necessary pH control was instituted 9 months after startup.

The lack of provision for additional firing of gas or oil is responsible for wide fluctuations in the quality and quantity of the flue gas because burning cannot be controlled. This makes both effective scrubbing and pH control difficult.

Operating and Maintenance Practices

Maintenance at the plant is minimal. There are no scheduled turnarounds for the scrubbers or incinerators. The fans are repaired periodically as necessary.

The pH control system was initially installed as a fully instrumented automatic system that used ammonia to control acidity. The plant, however, had continual problems with probes scaling and breaking. Thus, although the actual electronics worked well, the plant went to a once a day grab sampling method to avoid the probe problems. This method has led to some fluctuations in the pH of the recirculating water (Figure A1-5) because of the slow response time and because of the fact that

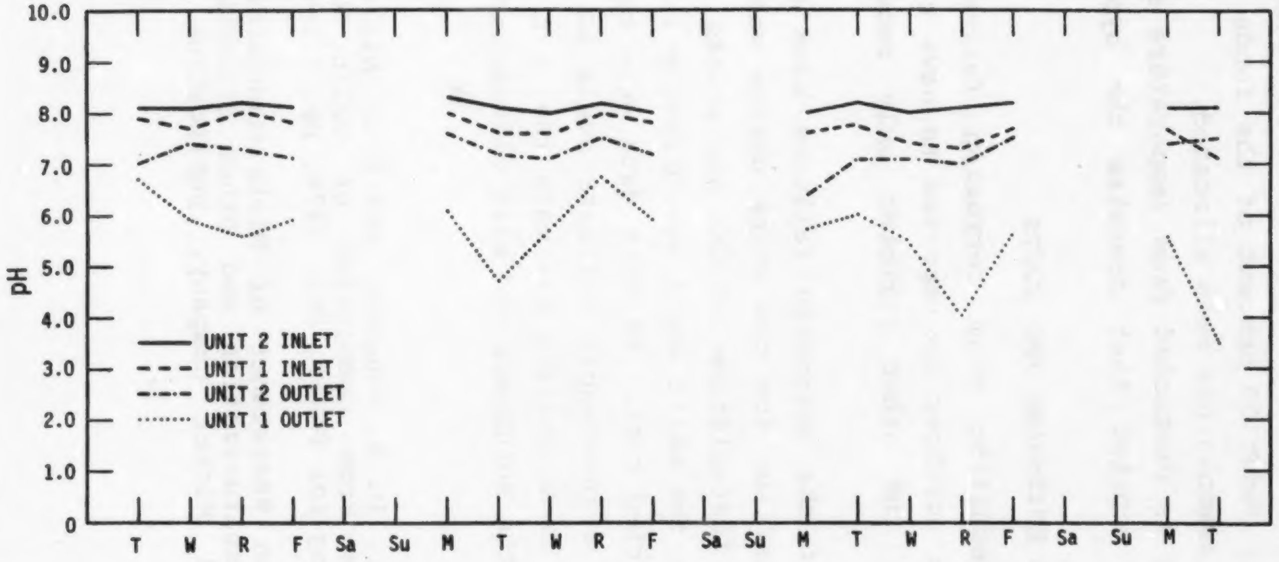

Figure A1-5. Variations in scrubber liquor pH over a 22-day period as measured in lab from daily grab samples (Mondays through Fridays).

pH is measured only 5 days a week while the plant operates 7 days a week. Fluctuations in the pH of the recirculating water are also indicated in Table A1-2. Another problem with pH control has been insufficient allocation of funds. In the last fiscal year, only about 30 percent of the funds needed to purchase sufficient ammonia has been allocated.

The scrubber is protected from temperature excursions by a high-temperature monitor that operates the bypass at 121°C.

CORROSION-RELATED EMISSIONS AND COSTS

Emissions resulting from corrosion failures have been significant. One scrubber is reported to have never met emissions standards; the other scrubber only recently achieved compliance.

The costs of the corrosion failures have been enormous. The cost of installing the new stack system was in excess of $1 million. The installation of the new stacks took 9 months, during which time the solid waste was directly landfilled at an additional unreported cost. No cost data were supplied for fan replacement, but a reasonable estimate would be $150,000. It was not possible to accurately estimate the cost of repairs and modifications to the scrubbers and mist eliminators.

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SOURCE 2

VENTURI SCRUBBERS SERVING MUNICIPAL INCINERATOR

SUMMARY

The facility consists of six furnaces that were each designed to burn 195 Mg per day of domestic refuse. Only five of the six furnaces are in use. Each of these five is now controlled by a venturi scrubber to reduce particulate matter emissions.

The venturi scrubber system has experienced both minor and major corrosion problems. The major problems have included premature failure of Incoloy ID fans and deterioration of the refractory brick stack lining in one of the three stacks. To date, it is estimated that these problems have cost in excess of $400,000.

The plant did not release any data on possible violations of particulate emissions standards that have been caused by corrosion-induced equipment failures.

SOURCE DESCRIPTION

Source 2 is a municipal incinerator that began operation in 1959. At the time of construction, it was the largest municipal incinerator facility in the United States. The plant burns approximately 970 Mg per day of domestic refuse; its operating schedule is 10 days on and 2 days off. The plant is located in a region that experiences severe winters.

Each of the six furnaces is designed to consume 195 Mg per day of domestic refuse. Each furnace has a primary and a secondary burning chamber. The grates in the primary burning chamber are of the inclined type and may be controlled either manually or automatically. Six fans with variable speed drives ($16\ m^3/s$) supply air to the furnaces for combustion. One auxiliary oil burner (3×10^9 J) is located in each of the primary and secondary burning chambers of each furnace. Auxiliary dampers controlled by an electric eye are located on both sides of the secondary chamber to allow air to enter when needed for further combustion of incompletely incinerated material. Ash from the incinerators is landfilled. Flue gases from the incinerators pass into the air pollution control system for particulate matter removal.

The original air pollution control system had six spray chambers. In each chamber, four banks of sprays had a capacity of 410 ℓ/min. Each chamber consisted of three passes; the final pass was designed to dry the flue gases.

The present air pollution control system was installed during 1969-1976. In 1969, an Overtron scrubber was installed on Furnace No. 2. In 1972, 1973, 1974, and 1976, a scrubber manufactured by Combustion Equipment Associates (CEA) was installed on each of the furnaces Numbered 3 through 6. In an attempt to reduce plant costs, Furnace No. 1 was abandoned; therefore, no pollution control devices were installed on the furnace. It was believed that the capacity of the five controlled furnaces would be adequate.

The venturi scrubbers are constructed with brick venturi throats and 316L stainless steel venturi cones. On each scrubber, the venturi is followed by a 12-ft diameter, stainless steel cyclonic separator, where tangential collection of the scrubbing liquor is achieved. The flue gases enter the venturi throat at a temperature of about 650°-760°C, and they exit the separator at a temperature of about 77°C. From the separator, the flue gases pass to a fan (Incoloy 800 impeller, carbon steel shaft, and stainless steel housing) and through ductwork to the stack. The ductwork is constructed of mild steel lined with a Ceilcote liner. The stacks are constructed of brick with an airspace annulus and a refractory-brick lining; the stacks are

76 m in height. Furnace No. 2 has its own stack; Furnace Nos. 3 and 4 share a stack; and Furnace Nos. 5 and 6 also share a stack.

Each of the venturi scrubbers uses 3400 ℓ/min of water. Of this, 3060 ℓ/min is recirculated, 380 ℓ/min is purged to the clarification system, and the other 230 ℓ/min is vented through the stack as water vapor. In the event of a temperature excursion, additional emergency water is available. The pH of the recirculating water is controlled by an automated system that uses sodium hydroxide to control acidity. The system is checked hourly by an engineer.

MALFUNCTIONS DUE TO CORROSION

The air pollution control system that was installed when the plant was constructed was a primitive system consisting of a water spray that impinged on the flue gases as they left the incinerator. Reportedly, the system had various materials and corrosion problems and was not very effective in removing particulate matter. Several experimental scrubbing systems were investigated before the Overtron and CEA scrubbers were chosen. Negligible data are available on these original and experimental systems.

The present air pollution control system has experienced a few costly corrosion problems which are detailed in the following subsections.

Scrubber Recirculation Pumps

The recycle pumps are constructed of rubber-lined mild steel. The linings were prone to damage caused by pieces of refractory that had broken from the venturi lining. The situation has been remedied by the installation of a stainless steel screen between each scrubber and its recycle pumps. Before this modification, the pump impellers had to be replaced frequently--sometimes as often as once a month.

Scrubber Internal Components

An inspection of the interior of one of the CEA scrubbers found it to be very clean, with only slight evidence of corrosion. A structural member just below the venturi was suffering from high velocity erosion. The venturi cones, which are constructed from 316 stainless steel, have a life of only 3 years because of erosion-corrosion. The scrubber shell, which was constructed from either 304 or 316L stainless steel, showed no evidence of corrosion.

Fans

Stress corrosion cracking of the ID fans is one of the more costly aspects of corrosion experienced by the scrubber system.

Each fan wheel is fabricated from Incoloy 800 and is welded to an Incoloy 800 hub on a carbon steel shaft. Because the Incoloy is susceptible to stress corrosion cracking in the weld region, fan life is limited to approximately 4 years. Figure A2-1 shows a stress corrosion crack running around the weld; the

Figure A2-1. Incoloy hub removed from the carbon steel fan shaft. A section of the hub has been cut away for metallographic analysis. A fracture resulting from stress corrosion cracking can be seen running in a semi-circle around the weld.

crack is most visible in the region of the cutaway (cutaway was removed for metallographic analysis after the development of the crack).

Each fan housing was originally constructed of rubber-lined mild steel. Wear and temperature excursions resulted in perforations of the lining. Particularly susceptible sections of the lining have been repaired by welding on stainless steel plates, which has sometimes resulted in further damage to the remaining rubber lining.

Ductwork and Stacks

The ductwork was constructed of carbon steel with a Ceilcote lining that failed because of poor application. The ductwork was recoated and has lasted well.

The stacks were designed for high-temperature service (315°-370°C). The present venturi scrubbers, however, use 10 times the quantity of water that the original spray chambers used; this results in lower gas temperatures (38°-95°C), high moisture content, and stack lining problems. One stack has been relined by placing chicken wire and gunite over the existing acid refractory brick; this nessitated constructing temporary ductwork to reroute the flue gases to the other stacks. The temporary ductwork, constructed from unlined mild steel, suffered severe corrosion, but it did serve the purpose for which it was constructed.

DESIGN EVALUATION

Materials of Construction

Overall, the materials of construction used in the air pollution control system have been adequate for the service conditions.

The stack problems have been typical of those experienced in scrubber retrofit situations, where the quantity of moisture in the flue gases is greatly increased over original design conditions and where the temperature of the flue gases is lowered.

These problems, however, were due to design rather than to materials of construction.

The failures of the fan impellers and hubs because of stress corrosion cracking may have been avoided if a more resistant alloy had been selected. Ti-6Al-4V, Hastelloy C, and Inconel 625 have all been found to have superior corrosion resistance in scrubber environments; Titanium 75A may also be satisfactory.[1] Both Hastelloy C and Inconel 625 would entail a higher capital investment than Incoloy 800, but the cost of fans fabricated from titanium would be comparable with the cost of Incoloy 800.[2] The higher cost of the Hastelloy C or Inconel 625 fans may be justified by reduced maintenance and replacement costs.

Plant Design

The plant experienced both minor and major design problems that have now been remedied.

The rubber linings of the recirculation pumps were damaged continually by pieces of refractory that had broken away from the interiors of the scrubbers. This costly problem was remedied by the installation of stainless steel screens between the scrubbers and the pumps; the screens remove the pieces of broken refractory.

The lining failed on one stack because the stacks were designed for a high-temperature, dry environment (315°-370°C), and the venturi scrubbers provided a low-temperature, high-humidity environment that was deleterious to the refractory brickwork. To date, only one stack has been repaired, but it seems likely that repairs will be required in the other two stacks in the near future. The problem could have been avoided if hot electrostatic precipitators had been installed instead of venturi scrubbers to prevent particulate pollution.

Some aspects of the plant design have helped to minimize the effects of corrosion. The use of a continuous automatic pH control system that performs to design specifications (pH control systems tend to be unreliable) is one of the primary factors in reducing scrubber corrosion. Materials such as stainless steels that would otherwise have failed in scrubber service have been used successfully with only minor corrosion problems. The incinerator design, which allows for auxiliary fuel firing and for the injection of additional combustion air, has also been beneficial because the fireman can more accurately control the furnace conditions, achieve more complete combustion and a more uniform flow of flue gases, and attain more effective scrubbing and better pH control.

Operation and Maintenance Practices

The plant operates on a planned maintenance schedule that helps to reduce equipment failures. The pH control system is serviced weekly and is checked hourly by an engineer. The fans are checked with a vibration meter every 2 hours.

CORROSION-RELATED EMISSIONS AND COSTS

The plant released only limited data on costs related to corrosion failures. They estimated that each fan failure costs $30,000 for materials, giving a total cost for fan failures of at least $200,000 over the life of the new scrubber system. Man-power costs for fan installation and the landfilling costs for disposing of the refuse that would have been incinerated were not disclosed. No data were supplied on the cost of relining the stack, but an estimate of at least $200,000 would seem reasonable.

The plant did not report any emissions problems related to corrosion failures.

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SOURCE 3

WET SCRUBBERS SERVING SEWAGE SLUDGE INCINERATORS

SUMMARY

This municipal sewage treatment plant utilizes four multiple hearth incinerators to dispose of sludges accumulated within the plant. Exhausts from each incinerator are treated for particulate removal by three-stage impingement plate scrubbers.

Corrosion has been a chronic problem in the fans and stacks and in the ducting connecting them to the scrubbers. The corrosive agents seem to be sulfuric acid and chlorides originating in the sludges and the scrubbing liquors. Corrosion is exacerbated by poor welding practices. No significant particulate emissions have resulted because of the corrosion, as corrosion has occurred downstream of the scrubbers. Costs of the corrosion damage appear to have been significant, but estimates for these costs are not available.

SOURCE DESCRIPTION

Source 3 consists of a set of four sewage sludge incinerators serving a large metropolitan sewage treatment plant. Each of the four incinerators is a multiple hearth incinerator with a quench chamber for cooling the flue gases and an impingement type tray scrubber for particulate control. The sewage treatment plant is more than 20 years old, and the incinerators are approximately 15 years old.

Approximately 18,000 Mg of sludge are burned in the incinerators each year. Sludge is drawn from both the primary settling chamber and the secondary treatment clarifiers. Sludge first passes through degritters to remove large abrasives that are difficult to pump and then to anaerobic sludge digesters. Digested sludge is thermally conditioned to facilitate dewatering; it is then thickened by sedimentation and dewatered by eight vacuum filters. Dewatered sludge fed into the incinerators from the vacuum filters contains only 50 percent water.

The sludge is self-burning, but the incinerators have the capability of using No. 2 oil or digester gas to aid in combustion. Each incinerator contains nine hearths, has a maximum capacity of 775 kg of sludge per hour, and can operate 24 h/da, 7 da/wk. Sludge enters the top of an incinerator where it is first dried on the upper hearths by hot, rising combustion gases and then burned as it moves slowly down through the lower hearths. Residual ash is removed at the bottom hearth. Temperatures in the furnace are about 320°C in the lower ash cooling hearth, 750° to 1100°C in the central combustion hearths, and 540° to 650°C in the upper drying hearths. Ash resulting from the incineration process is discharged into a water-filled tank and pumped as a slurry to lagoons located at the treatment plant sites.

Exhaust gases from each incinerator pass through a quench chamber, a scrubber, and an induced draft fan, and then out through a stack. The incinerators, quench chambers, and scrubbers are located inside a building while the fans and stacks are on the building roof.

Each scrubber contains three impingement plate trays with scrubbing water flowing across the top of each tray and water sprays beneath each tray. Scrubbing water (as well as quench water) is once through, and is obtained from the plant's secondary clarifiers. Each scrubber also has a chevron-type liquid entrainment separator. Scrubber exit temperatures are approximately 95°C. Temperature monitors at the scrubber outlet are interlocked to emergency bypass dampers. The monitors will actuate the dampers when high-temperature excursions are detected such as during a loss of scrubber water.

The fan wheels and chevron mist eliminators are constructed of type 316 stainless steel. Sections of the ductwork leading from the scrubbers to the fans and from the fans to the stacks are type 302 stainless steel, and other sections are type 304 stainless steel. Much of this ductwork is thermally insulated. The scrubber vessels, stacks, and most other scrubber components are also stainless steel, but records listing the specific alloys used are not available.

MALFUNCTIONS DUE TO CORROSION

Corrosion in the Source 3 scrubber systems seems to be confined to components located outside the incinerator building (i.e., on the incinerator roof). Most of the fan components and the ductwork were replaced after 5 years of service because of corrosion. Some of these components have been repaired again since then, and most will require replacement a third time in the near future (Figure A3-1). All four stacks have also been replaced, and may likewise require replacement again (Figure A3-2). Corrosion in the stacks and ductwork is most severe at the welds. Plant personnel have reported little corrosion in the quench chambers or in the scrubbers.

DESIGN EVALUATION

The probable agents of corrosion at Source 3 are sulfuric acid and chlorides. Dried municipal sewage sludges generally contain between 1 and 2 percent sulfur that can oxidize during incineration to form sulfur dioxide and sulfur trioxide (temperatures within the incinerator are not sufficiently high to form nitrogen oxides).[1] Sulfur trioxide formed in this manner can combine with the scrubber water to form sulfuric acid. Chlorides can come from two sources in the scrubbing system. Secondary clarification water, such as that used for the Source 3 scrubbing liquor, typically contains 90 ppm chlorides, and sludge incinerator exhaust gases typically contain 750 ppm hydrochloric acid.[1,2]

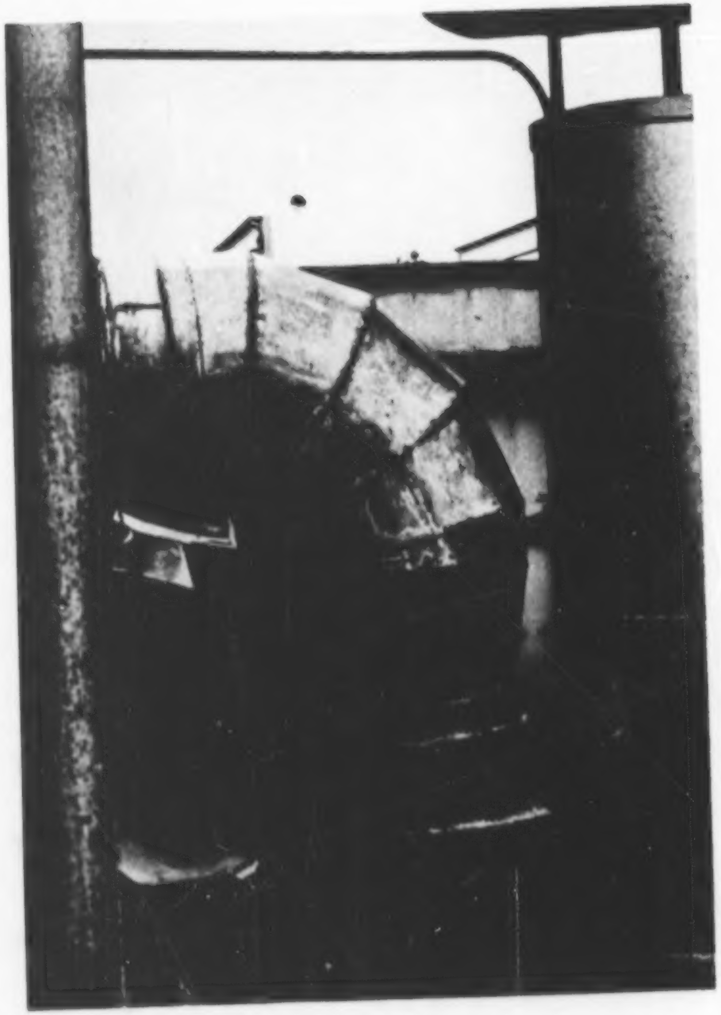


Figure A3-1. Stainless steel ducting (alloy unknown) leading from a scrubber to the fan inlet. Severe corrosion is visible at each weld. Less severe corrosion is visible elsewhere.

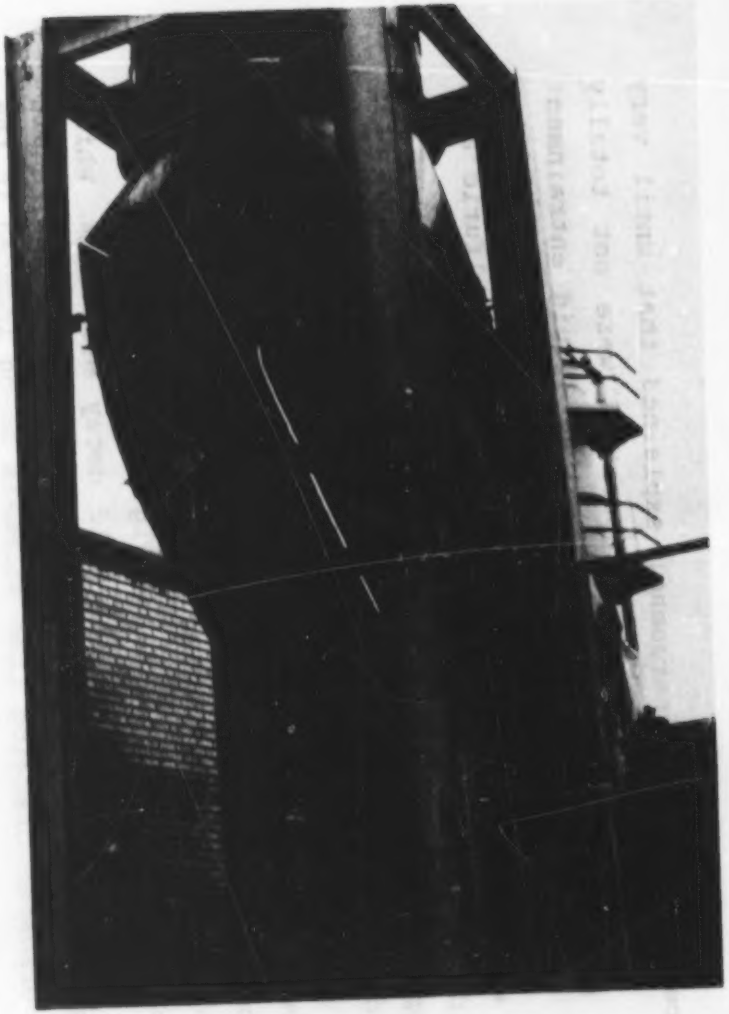


Figure A3-2. Base of a scrubber stack showing severe corrosion at welds (light is visible along corroded weld seams).

Source 3 maintenance personnel explained that until very recently, the liquid entrainment separators were not totally effective (recent modifications have solved liquid entrainment problems). Poor liquid entrainment separation resulted in mist carryover with the flue gases, which transported sulfuric acid and chlorides to the ductwork, stacks, and fans.

The optimum alloy choices for each component have not been established. Several stainless steel alloys including types 302, 304, and 316 have been used in the system, but plant personnel have not kept track of which alloys were used in particular components. Most corrosion seems to be concentrated around welds, which suggests that poor welding practices are as great a problem as alloy selection (Figure A3-3). Corrosion in the welds is probably due to the weld decay mechanism, while corrosion immediately adjacent to the welds could be the result of stress corrosion cracking (the stresses being induced in the metal by the heat of the welding process).

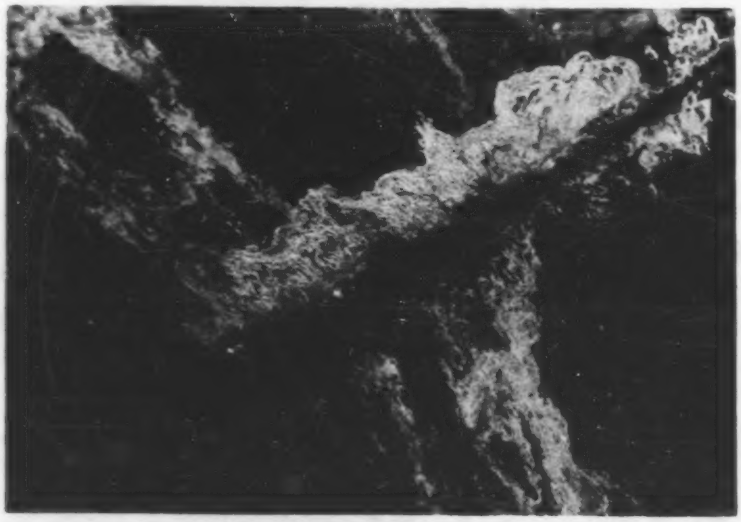


Figure A3-3. Closeup of a weld in stainless steel ducting showing corrosion at weld.

CORROSION-RELATED EMISSIONS AND COSTS

There have been virtually no corrosion-related emissions from the Source 3 scrubbers, because corrosion generally has occurred in components downstream from the scrubber vessel. The main effect of the corrosion has been reduced availability of the scrubber systems during repair operations. Corrosion of the stacks and ducts may have also had a moderate impact on plume rise and dispersion.

The costs of scrubber system corrosion at Source 3 have probably been significant, but estimates of the costs are not available.

REFERENCES

1. Compilation of Air Pollution Emission Factors, Third Edition. EPA-AP-42, Part A, August 1977.
2. Lamb, J. C., III. Advanced Treatment of Municipal Wastewaters-A Survey of Current Practices. Department of Environmental Sciences and Engineering, University of North Carolina. Publication ESE-361, November 1973.

SOURCE 4

ELECTROSTATIC PRECIPITATOR SERVING GLASS-MANUFACTURING PLANT

SUMMARY

Source 4 produces glass in two natural gas-fired melt furnaces. Exhausts from the two furnaces pass through a single quench chamber for cooling and through an electrostatic precipitator (ESP) for particulate removal. During the first 5 years of ESP operation, there have been chronic corrosion problems in ductwork and dampers between the furnace exhausts and the quench chamber. The ESP has been bypassed approximately 1 percent of the furnace's production time to facilitate repair of corroded ductwork.

The plant has tried various steels, including stainless steels, but none has lasted longer than 1 year in the hot furnace exhausts. The ESP manufacturer has assisted the plant in a program to test various alloys. Type 310 stainless steel appears to be the most durable alloy tested.

The plant has spent $50,000 to $100,000 per year in maintenance of the ESP system. Most of these expenses have been for replacement of corroded ductwork and dampers.

SOURCE DESCRIPTION

The facility consists of two melt furnaces that exhaust to one ESP system for particulate removal. The furnaces, which are designed to operate continuously, use about 51,000 m^3 of natural gas per day. The furnaces have been in operation about 7 years.

Source 4 was initially required by the State agency to install a particulate control system on the furnaces prior to plant startup; because this compliance schedule caused design problems, however, the agency gave a 1-year extension to Source 4 to finalize the designs and to install particulate controls. This time was used to choose between ESP, scrubber, and fabric filter systems; to select the manufacturer; and to design the system with the manufacturer's assistance. The ESP was placed in service about 1 year after plant startup, and it passed the compliance tests 3 months later.

Exhausts from each furnace are normally ducted into a single quench chamber preceding the ESP. Gases enter the quench chamber at 600° to 650°C and exit at a temperature of about 270°C. The quench chamber uses air-atomized water to cool the furnace gases. Water use is about 240 ℓ/min--all of which is evaporated. The exhaust gases contain silicate particulate as well as traces of fluorides and lead oxides. A draft is induced through the quench/ESP system by a fan located between the ESP and the main plant stack. Airflow through the system is about 11.3 m^3/s.

During ESP or quench chamber upset conditions, the furnace exhausts can bypass the particulate control system and exit through emergency stacks. Each furnace has its own emergency bypass stack equipped with a top cap and two shutoff dampers to divert gas flow where the emergency stack and quench chamber ducts join. The furnaces, a portion of the ductwork, and the bypass dampers are located indoors. The quench chamber, ESP, fan, and remaining portions of the ductwork are located outdoors. Because of severe winters at the plant site, the ESP is well insulated, and its hoppers are completely enclosed so that condensation will not occur.

The original materials of construction in the ESP system included Corten for the shell, quench chamber, ductwork, and electrodes; 316L stainless steel for the dampers; 316 stainless steel for the quench chamber spray nozzles; and mild steel for the fan.

MALFUNCTIONS DUE TO CORROSION

High-Temperature Ductwork

The high-temperature furnace gases have caused extensive corrosion in the ductwork between the furnaces and the quench chamber. Corten failed after a few months service in this environment. The plant replaced sections of corroded Corten ducting several times and then switched to 316L stainless steel ducting; this material failed in as little as 3 months. The plant has begun a test program with the assistance of the ESP manufacturer to determine the most effective alloy for this environment. It appears that 310 stainless steel is the most effective material; several sections of 310 ductwork are still in service after 6 months.

Dampers and Bypass Stack Caps

The dampers have had corrosion problems similar to those in the high-temperature ductwork, but the corrosion is more severe. The dampers are exposed to the highest temperatures in the system without the cooling effects of ambient air that benefit the ductwork. The best service thus far has been provided by 310 stainless steel.

The Corten bypass stack caps have also experienced high-temperature corrosion problems, but the problems are less severe because exposure to furnace exhausts is intermittent. The caps have been replaced only once in 7 years.

Other ESP System Components

No significant corrosion problems have been experienced in the lower temperature portions of the ESP system. Corten steel has served well in the quench chamber, ESP, and connecting ductwork. The 316 stainless steel quench nozzles have lasted 5 years; they failed due to erosion rather than corrosion. Finally, mild steel has proven to be appropriate for the fan. The fan is cleaned and balanced annually and has experienced no problems.

DESIGN EVALUATION

Corrosion problems in metal ductwork containing high-temperature gases are difficult to solve. Present technology in refractory metals does not provide alloys that are resistant to corrosion in all high-temperature applications. Fluorides and lead oxides in the furnace gases have a synergistic effect with the elevated temperatures in causing corrosion.[1] Fluorides alone have the potential to cause significant corrosion in 310 stainless steel at temperatures above 400°C.[2] The use of 310 stainless steel for ductwork has mitigated the corrosion but it is doubtful that this alloy will eliminate corrosion entirely. The best that can be expected with 310 stainless steel is a longer service life between corrosion failures. Source 4 plans to use refractory-lined mild steel ductwork on any new ESP systems it might install.

One design option that might reduce the costs of corrosion failures is to relocate the quenching chamber further upstream to reduce the linear footage of ducting exposed to the highest temperatures.

CORROSION-RELATED EMISSIONS AND COSTS

Corrosion has increased particulate emissions at the plant in two ways. The most significant increase occurs when a duct failure necessitates bypassing of the ESP system; the plant estimates that this has occurred approximately 1 percent of the operating time of the furnaces. The second most significant increases occur because noncatastrophic duct failures allow in-leakage into the system. Because the ESP system was designed with minimum spare capacity, the increased flow requirements resulting from in-leakage exceed the design capacity and reduce the ESP's particulate removal efficiency. Source 4 plans to purchase a second ESP to provide an increased factor of safety in the system.

Annual operation and maintenance costs for the ESP system, not including power consumption and depreciation, are estimated at $50,000. These costs are primarily due to replacement of corroded ductwork. The particulate control system cost approximately $1.2 million when installed.

REFERENCES

1. Brasunas, A. deS. Alloy Behavior at High Temperatures, Chapter 13, NACE Basic Corrosion Course. National Association of Corrosion Engineers, Houston, Texas, 1977.

2. Moran, J. J., Jr. Corrosion at High Temperatures, Chapter 12, NACE Basic Corrosion Course. National Association of Corrosion Engineers, Houston, Texas, 1977.

SOURCE 5

FABRIC FILTER SERVING CAST IRON FOUNDRY CUPOLAS

SUMMARY

This cast iron foundry operates a cupola battery that produces iron for a variety of cast iron products. A shaker-type fabric filter is used to control particulate emissions from the cupolas. The filter provides adequate control of particulate emissions when operating properly, but corrosion failures and fan abrasion have resulted in several fabric filter bypass episodes since the foundry began production. It is estimated that particulate emissions during bypass of the filter are approximately 270 kg/h. It is also estimated that the corrosion in the fabric filter system has cost the source more than $250,000 since plant startup.

Filter corrosion is the result of sulfuric acid and other impurities condensing from the hot flue gases on the cooler filter surfaces. Elimination of this acid corrosion is difficult to accomplish without costly modifications. Source 5 is investigating the possibility of replacing the quench chamber with a recuperative heat exchanger. This modification may prevent acid condensation by eliminating the source of most of the moisture in the flue gases, but it would cost up to $900,000.

SOURCE DESCRIPTION

Source 5 operates a pair of 31-Mg/h cast iron cupolas with afterburners and a fabric filter to control carbon monoxide and particulate emissions. The cupolas operate on alternating days for melts lasting 16 to 20 h. The foundry and associated air pollution control equipment began operation in 1974.

Each cupola is a carbon steel cylinder lined with refractory brick. Prior to ignition, a cupola is charged with scrap steel (predominately automobile scrap), metallurgical grade coke, and limestone flux. Additional raw materials are added as needed during a melt to maintain production. Combustion gases exit at the top of the cupola through an afterburner section where the carbonaceous particulates and carbon monoxide in the gases are oxidized. The afterburners for each cupola can use natural gas or oil for fuel and have a maximum heat input of 6.8×10^9 J/h. Flue gases exit the afterburners at 700°C.

Cupola exhausts pass from the afterburner through brick-lined carbon steel duct work to a quench chamber. The 4-m diameter quench chamber is constructed of carbon steel, lined with luminite gunite. A series of water sprays with a capacity of 560 ℓ/min cool cupola exhausts to between 230° and 260°C. Temperature sensors at the quench chamber outlet control the water flow through the sprays. These sensors will also trigger the opening of the cupola bypass caps should the quench sprays fail to cool the flue gases below the temperature limits of the filter bags. The relatively large quench chamber reduces gas velocity so that the quencher also serves as a settling chamber to remove the largest sized particulates.

Unlined carbon steel ducting leads from the quench chamber to the system fan. The carbon steel radial fan is designed to draw 75 m^3/s of cupola exhausts through the quench system and force it through the fabric filter.

The fabric filter is a 14-compartment, shaker-type design with a roof monitor exhaust. The filter contains 1200 silicone-treated glass bags having a combined surface area of 7080 m^2. At the designed airflow, the filter has an air-to-cloth ratio of 2.1 to 1. Collected dust falls from the bags into collection hoppers that empty into screw conveyors. The screw conveyors discharge into covered bins that are emptied as needed. The fabric filter enclosure is constructed of a carbon steel framework and corrugated transite walls.

MALFUNCTIONS DUE TO CORROSION

The quench chamber and the ductwork have experienced few corrosion problems since installation of the filter. The fan has suffered from abrasion, however, and the carbon steel portions of the filter have suffered from corrosion.

Fan

The fan is located on the dirty side of the fabric filter where particulate is present in the gas stream. This particulate abrades the fan blades so that they eventually become unbalanced or their clearance with the fan casing becomes too great. The fan has required major maintenance or replacement at least once a year since startup. During unexpected fan outages, the cupola emissions must be exhausted untreated through the cupola bypass caps.

Source 5 is experimenting with surface treatment of the fan blades as a method of reducing wear. Fan components subject to high wear are sprayed with a chromium-nickel treatment. High-magnesium wear plates have also been used. These measures seem to reduce wear although experiences with these measures have been too short to determine their overall effectiveness.

Fabric Filter

The fabric filter has suffered corrosion of all carbon steel parts, including the tube sheet, bag hangers, dust hoppers, and structural members of the filter enclosure. Corrosion is caused by the condensation of sulfur oxides from coke combustion with the water vapor from the quenching, forming acids on filter surfaces. Acid condensation is most frequent during winter startup sequences. The plant has had to replace or repair many filter components and it must sandblast and paint steel parts as frequently as once a year.

DESIGN EVALUATION

The design of the fabric filter system at Source 5 provides adequate control of cupola emissions. Several changes could be made, however, to reduce fan abrasion and filter corrosion, thereby increasing system reliability.

Fan abrasion could be avoided if the fan was relocated to the clean air side of the filter. To alter the fan to this configuration, however, would require a major rebuilding of the filter roof monitor exhaust and the installation of a stack.

The filter has two design features for minimizing corrosion. These features are the construction of the filter enclosure so that structural steel is outside the corrugated transite walls, away from the hot sulfur-bearing flue gases; and the use of protective coatings to protect these and other steel parts from corrosion. These design features have helped reduce the severity of corrosion, but they have not proven to be a total solution. The structural steel is still subject to some corrosion in its outside location, and steel components inside the filter are subject to the full effects of acid condensation. The plant has experimented with several coatings, but most have failed in less than a year. The present high-temperature epoxy coating has provided more than 15 months service.

Source 5 is considering the replacement of the quench chamber with a recuperative heat exchanger system. This system would cool cupola exhausts without increasing the moisture content of the flue gases, which would reduce the potential for condensation in the filter. The heat removed by the heat exchanger might be usable for plant heating and for preheating the combustion air injected into the cupola. This system is expected to cost between $650,000 and $900,000.

CORROSION-RELATED EMISSIONS AND COSTS

Control system corrosion failures have increased particulate emissions at Source 5. Corrosion-related emissions are predominantly in the form of control equipment bypass episodes because of unexpected corrosion failures. The filter system has had several periods of uncontrolled emissions lasting 2 to 3 days since plant startup. Most of these periods were due to fan outages or because the sandblasting and painting of the filter required more than the annual 10-day period reserved for major plant maintenance. During normal operation, the filter removes up to 99 percent of cupola particulate emissions and emits no visible particulates. Decreased performance can occur, however, because of bag failures or corrosion of the tube sheets, bag hangers, and dust hoppers. Uncontrolled emissions from a cupola battery such as at Source 5 have been estimated to be in the range of 270 kg/h.[1]

The original cost of the filter system, including the fan and the quench chamber, was about $175,000. Since installation of the filter, the plant has spent about $25,000 annually to sandblast and paint the filter and up to $20,000 annually to repair abraded fan parts. Additional costs have been incurred because of corrosion damage to the hoppers and other filter components. In six years of filter operation, corrosion-related maintenance costs have probably totaled more than $250,000.

REFERENCE

1. Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes, EPA-340/1-78-004, 1978.

SOURCE 6

FABRIC FILTER SERVING CAST IRON CUPOLA

SUMMARY

This facility produces iron-shot abrasives in a cast iron cupola. A fabric filter was added after the facility operated uncontrolled for 1 year. The uncontrolled cupola can liberate approximately 8.5 kg of particulate per Mg of iron produced.[1]

At the time of installation, the filter provided adequate control of emissions, but its efficiency and reliability deteriorated significantly over time as a result of corrosion. The causes of filter corrosion were poor control of the acid dewpoint as a result of poor filter insulation, and mist carryover from the quench chamber. After only 5 years of service, the filter system, representing a capital investment of approximately a quarter million dollars, was replaced with a venturi scrubber system.

SOURCE DESCRIPTION

The typical cupola production schedule is one 10-h shift per day, 250 days per year. Approximately 900 kg of scrap steel (predominately automobile scrap), 135 kg of metallurgical grade coke, and limestone flux are added to the cupola each hour. The cupola was placed into service more than 6 years ago, and it operated for 1 year before the fabric filter was added to control particulate emissions.

A quench chamber was used for cooling the cupola emissions to a temperature compatible with the fabric filter. Cupola exhausts entering the quench chamber at 980°C were cooled to

170° to 190°C before they entered the fabric filter for particulate removal. The pulse-jet fabric filter was equipped with a thermocouple for recording inlet gas temperatures, a bypass damper activated by the thermocouple, a differential manometer for indicating pressure drop across the filter medium, and a magnehelic gauge indicating pulse-air pressure. Under normal conditions, fabric filter differential pressure varied from 0.25 kPa immediately after a cleaning cycle to 2.2 to 2.5 kPa just prior to a cleaning cycle. Pulse-air pressure was maintained between 550 and 690 kPa.

The filter was constructed of epoxy-lined steel, filter bags were made of felted Nomex, and the quench chamber was constructed of uncoated mild steel. Dust was removed from the filter hoppers through a rotary airlock and a screw conveyor. The filter system was designed to treat 18.9 m^3/s of cupola gases at 980°C.

After 5 years of operation, the fabric filter was replaced with an adjustable throat venturi scrubber. The 304 stainless steel venturi scrubber is designed to treat 21.2 m^3/s of cupola gases at 980°C. Scrubbing water is recirculated and treated for pH control. The new scrubber system is equipped with temperature sensors and fan ammeters; water flow meters and pH monitors are presently being installed.

MALFUNCTIONS DUE TO CORROSION

Corrosion became a problem in the fabric filter system after 2 years of operation. By the end of 5 years, the system was unusable; that is, corrosion had penetrated the filter walls and hoppers, weakened the structural supports, and caused failure of 80 percent of the ducting. During the life of the unit, bag cages and bag hangers suffered repeated failures. The fan was removed from service because of corrosion and wear about 1 year after the filter was removed from service. The quench chamber, however, provided good service throughout the life of the fabric filter system, although moderate corrosion had become evident by the end of 5 years use.

The cause of corrosion was acid attack of mild steel structures within the filter. The acids were formed by combustion products, such as nitrogen oxides and sulfur oxides, that had condensed with water on the cold outer surfaces of the filter and ductwork.

DESIGN EVALUATION

Design requirements for a fabric filter system restrict temperatures to a specific range. Ideally, the quench chamber should cool the gases to a temperature below the limitations of the bag fabric yet above the sulfuric acid dewpoint. Temperature control in a cupola is complicated by startup sequences, shutdown sequences, and numerous charging operations during each shift, which cause the exhaust temperatures to vary.

Source 6 indicated that moisture carryover from the quench chamber was a problem throughout the life of the filter. Even when quench water was completely evaporated, condensation within the filter was likely because it was not insulated, and it was located outside where it was exposed to the severe winters at the plant site. The system was especially susceptible to condensation as the filter cooled after shutdown of the cupola.

Source 6 listed several filter problems in addition to corrosion. First, the actual airflow was about half that of the designed airflow; this reduced draft in the cupola limited the plant production rate. Second, sparks penetrated the quench chamber and on rare occasions caused fires in the filter; these fires may have damaged the epoxy coating on the structural steel. Third, the rotary airlock and the screw conveyor were subject to plugging, which the plant management attributed to tramp materials entering the filter. Because of problems with the fabric filter, especially with quench chamber moisture carryover, Source 6 replaced the filter with the scrubber system.

CORROSION-RELATED EMISSIONS AND COSTS

Corrosion of the fabric filter greatly increased the particulate emissions of Source 6. The manufacturer reported the efficiency of the filter to be 99.9 percent, but the plant manager estimated the efficiency to be only 90 percent throughout most of the 5 years of filter operation. This low efficiency was due in part to corrosion. The plant was frequently out of compliance during this period; during the final 1½ years of filter operation, the plant was out of compliance most of the time. The enforcement agency allowed the plant to operate in this manner while attempts were made to improve the system. Because compliance problems were obvious, neither Source 6 nor the State performed a stack test on the filter.

Neither the filter manufacturer nor the distributor accepted responsibility for any of the corrosion problems or other design problems. Source 6 was unable to invoke a guarantee, written or implied, to recover any of the financial losses of filter failures. The costs of filter system malfunction included total depreciation of the $270,000 filter system in less than half of its planned 15- to 20-year life, an estimated $30,000 to $40,000 in annual maintenance costs, and an undetermined amount of lost production. The capital costs of the filter failure can be attributed almost entirely to corrosion. More than 60 percent of the annual maintenance costs were due to bag failures rather than corrosion, however, and nearly all the loss of production costs were due to the inadequate flow rate rather than corrosion.

REFERENCES

1. Formica, P. N. Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eightly Processes. EPA-340/1-78-004. April 1978.

SOURCE 7

FABRIC FILTERS SERVING CAST IRON FOUNDRY CUPOLAS

SUMMARY

This foundry operates two cupola lines that produce a variety of cast iron products. Cupola emissions were originally uncontrolled, but the plant became subject to State Implementation Plan (SIP) emission regulations in the early 1970's. Fabric filters were then retrofitted to each cupola. These filters performed satisfactorily at first, but fan abrasion and corrosion problems appeared in each filter system within a year. Fan and filter failures have resulted in a number of control equipment bypass episodes and have cost a considerable amount in replacement or repair of equipment. It is estimated that particulate emissions during bypass of the filter are approximately 150 kg/h for each cupola line. It is also estimated that filter system corrosion has cost the source in excess of $300,000 in 8 years of operation.

Filter corrosion is due to the difficulty in maintaining filter temperatures above the sulfuric-acid dewpoint. Acid condensation is especially severe during cold startup of a fabric filter. Elimination of dewpoint troubles may require costly design changes or changes in operating procedures. Changes that may be required include the improving of filter insulation, the preheating of the filters prior to cupola and quench startup, or the replacement of the water quench with recuperative heat exchanger.

SOURCE DESCRIPTION

Source 7 operates two cast iron cupola batteries with a fabric filter on each for control of particulate emissions. Each battery includes two cupolas that operate on alternating days to facilitate maintenance. One battery has an 18 Mg/h melt rate and operates 24 h/day while the other battery has a 16 Mg/h melt rate and operates 16 h/day. The fabric filters were retrofitted to the cupolas in 1972 and 1973.

Each cupola is a carbon steel cylinder lined with refractory brick. Prior to ignition, a cupola is charged with scrap steel (predominately automobile scrap), metallurgical grade coke, and limestone flux. During the melt, additional raw materials are added as needed to maintain production. Combustion gases exit at the top of the cupola through an afterburner where any carbonaceous particulates or carbon monoxide remaining in the gases are oxidized. Each afterburner contains two burners that can use natural gas or oil for fuel and that have a maximum heat input of 4.6×10^9 J/h. Flue gases exit the afterburner at 700° to 1000°C.

Cupola emissions are ducted to a quench chamber through water-cooled carbon steel. The quench chamber is a 3-m diameter carbon steel cylinder containing a series of sprays for cooling the cupola exhausts below the temperature limitations for the filter material. Each spray system has a maximum capacity of 260 ℓ/min. The quench chambers are lined with a layer of luminite gunite. The relatively large quench chambers reduce gas velocity so that the chambers also serve as settling chambers for removal of the largest sized particulates. Temperature sensors at the quench chamber outlets control the water flow rates in the spray sections. In addition, these sensors will trigger the opening of the cupola bypass caps whenever a failure occurs in the quench chamber. During normal operations, quench chamber exhausts vary between 230° and 260°C.

Cooled cupola exhausts exit the quench chambers through unlined carbon steel ducting to the cupola fans. Each cupola battery has an identical carbon steel centrifugal fan designed to draw 34 m^3/s through the quench chamber. The quenched cupola exhausts pass through carbon steel ducting to the fabric filter inlets.

The two fabric filters are similar in design, each having 10 compartments, shaker-type cleaning, and roof monitor exhausts. Each filter contains 600 silicone-treated glass bags with a combined surface area of 3540 m^2. During typical operation, a filter's air-to-cloth ratio is 1.9. Collected dust falls from the bags into collection hoppers that empty into screw conveyors. The screw conveyors discharge into covered bins that are removed for disposal as needed. The fabric filter enclosures are constructed of corrugated transite sheeting attached to a carbon steel framework.

MALFUNCTIONS DUE TO CORROSION

The quench chambers and the ductwork have experienced few corrosion problems since installation of the filters. The fans and the filters, however, have not provided satisfactory service. The fans have suffered from abrasion, and the filters have suffered from acid dewpoint corrosion.

Fans

The fans are located on the dirty side of the fabric filters where particulate is present in the gas stream. This particulate abrades the fan blades so that they eventually become unbalanced or their clearance with the fan casings becomes too great. The fans have required major overhaul or replacement about once a year because of this abrasion. Unexpected fan outages require about 3 days to repair, during which time the cupolas must exhaust uncontrolled through the bypass caps.

The plant is presently experimenting with surface treatment of the fan blades. The plant has used high-magnesium wear plates and has sprayed fan parts with a chromium-nickel treatment. These measures seem to reduce wear, although experience with these measures has been too short to make a final determination of their effectiveness.

Fabric Filters

The fabric filters have suffered corrosion of all carbon steel parts. Corrosion appeared within the first year of filter operation and has at times threatened the structural integrity of the filter enclosure. In 7 years of operation, each filter has required replacement of the tube sheet, the perimeter H-beams (Figure A7-1), the bottom hoppers, and the bag hangers. During this same period, the catwalks and stairways have been partially replaced. The plant now sandblasts and paints the steel structures about once a year.

The filter corrosion is caused by acid condensation resulting from the combustion products of sulfur from the coke combining with moisture added during quenching. Corrosion is most severe on cooler surfaces in the filter where condensation is most frequent (Figure A7-2). The plant reports that condensation is more likely during winter startup sequences than during summer startup sequences or during shutdown sequences. The intermittently operated cupola battery suffers less severe filter corrosion than the continuously operated battery, in spite of a presumably larger number of cold startups.

DESIGN EVALUATION

The design of the fabric filter systems at Source 7 seems to provide adequate control of particulate emissions from the cupolas. From a corrosion standpoint, however, several design changes could have increased system life and reliability. In fairness to the plant management, it should be noted that the

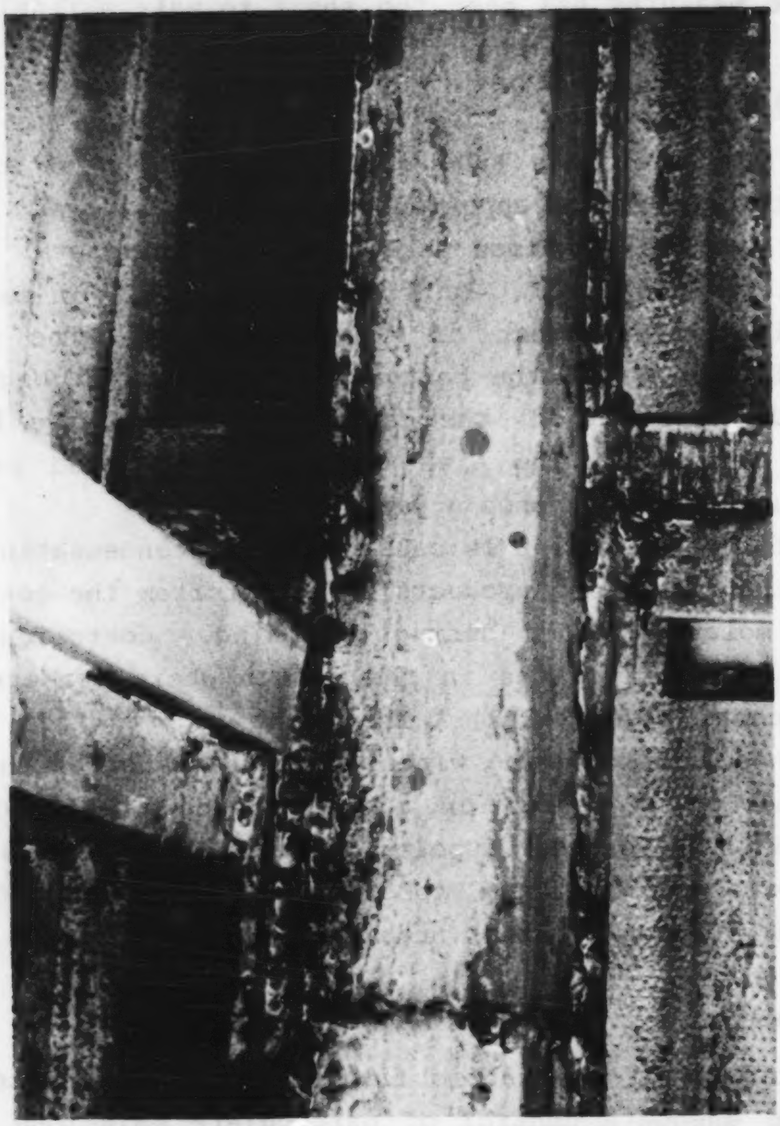


Figure A7-1. Inside Source 7 fabric filter showing structural steel corrosion and new cross-members welded alongside weakened original cross-members.

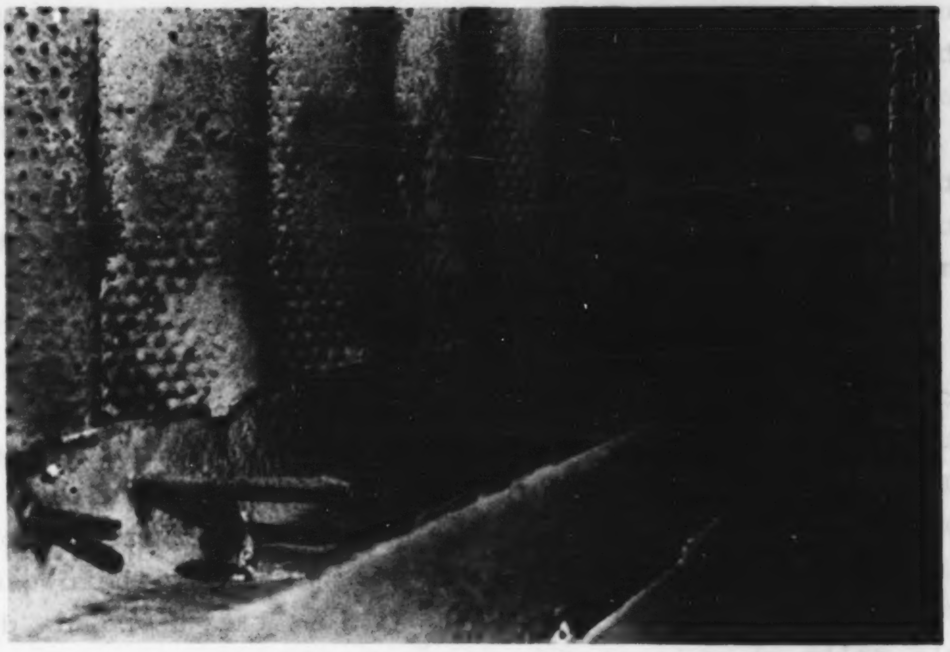


Figure A7-2. Closeup of Source 7 fabric filter cross-member showing that dewpoint corrosion is more severe along surfaces nearest the cool outer wall.

severity of filter corrosion proved to be greater than anticipated during the design phase, and that many design options that could have reduced corrosion problems would have been considerably more expensive.

The fan abrasion problems might have been avoided during filter system design by locating the fans on the clean side of the filters. To alter the filters to this configuration after they have been constructed would probably be prohibitively expensive because the roof monitor exhausts would have to be reworked, the fans would have to be moved, and stacks would have to be built. The present experimentation by Source 7 with wear plates and surface treatments may increase fan life sufficiently so that the present configuration will be acceptable.

Filter corrosion could be reduced in at least three ways. First, corroding filter parts could be reconstructed of corrosion-resistant alloys. Such alloys would be excessively expensive, however, and the coupling of these alloys to existing carbon steel parts could cause galvanic corrosion of the latter. Second, Source 7 could continue to rely on protective coatings to reduce corrosion, but experience thus far indicates that coatings are not a total solution. A third way to mitigate filter corrosion is to achieve better control of the acid dewpoint within the filter.

Improving dewpoint control seems to be the most practical way of reducing filter corrosion. Dewpoint control could be improved by a combination of design changes and changes in operating procedures. One design change that could help is the rebuilding of the filter enclosures and the hoppers with a thick layer of thermal insulation on the outside. Concurrent improvements in quench control instruments might allow their use for preventing temperature excursions below the dewpoint during cupola melts as well as for preventing high-temperature excursions. Condensation during cold startup would not be addressed by these measures, however. Startup condensation could be reduced by preheating the filters before the cupolas and quench sprays are started. The afterburners might serve as preheaters if they could be operated at a rate low enough to prevent damage to the filter bags.

CORROSION-RELATED EMISSIONS AND COSTS

Control system corrosion failures increase particulate emissions substantially at Source 7. Corrosion-related emissions are predominately in the form of bypassing of the control system because of unexpected corrosion failures. Uncontrolled emissions from cupolas such as at Source 7 have been estimated to be in the range of 150 kg/h.[1]

Each of the two filter systems has had several periods of uncontrolled emissions lasting 2 to 3 days since their installation. Most of these periods were due to fan outages. During normal operation, the filters remove up to 99 percent of the cupola particulate emissions and emit no visible particulates. Decreased performance does occur, however, because of bag failures or corrosion in the tube sheets and bag hangers. During the inspection of Source 7, a light to moderate haze was visible at the roof monitor exhaust for one filter.

The original cost of the pollution control system, including fans and quench chambers, was about $1 million. The major effect of the corrosion has been a reduction in the useful life of the equipment. It is expected that the filter enclosures will have to be rebuilt in the next several years. In addition to reducing the life of this capital equipment, corrosion-related maintenance costs have been substantial. Costs of fan repairs and the painting of the filters have probably exceeded $30,000 per year. In addition, approximately $25,000 was required to rebuild the filter hoppers. Corrosion-related costs in the filter systems have probably totalled more than $300,000 since installation of the filters.

REFERENCE

1. Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes, EPA-340/1-78-004, 1978.

SOURCE 8

WET SCRUBBERS SERVING OPEN HEARTH FURNACES

SUMMARY

This source is a steel mill using retrofitted wet scrubbers to control particulate emissions from three open hearth furnaces. The scrubbers reduce emissions to well below the applicable regulatory standards, but corrosion in scrubbing water treatment system components has caused the mill to bypass the scrubbers on numerous occasions. Corrosion has been caused primarily by poor reliability in the pH probes that control lime additions. Inappropriate materials choices have also contributed to the corrosion.

Uncontrolled particulate emissions during scrubber bypassing episodes have been about 23 Mg/day. Based on the number of malfunctions requiring bypassing of the scrubbers, Source 8 may have emitted as much as 450 Mg of particulate during the first year of scrubber operations. The costs of the corrosion failures have totalled more than $70,000 in replacement parts and labor.

SOURCE DESCRIPTION

Source 8 produces steel in three open hearth furnaces that use No. 2 and No. 6 oils as fuel. The mill operates only two furnaces at a time to facilitate periodic furnace maintenance without interrupting continuous production.

Furnace exhausts have been treated for particulate removal by a battery of six parallel scrubbers since the fall of 1978. These scrubbers are designed so that only three are in use while the other three are being cleaned and/or repaired. The old furnace stacks are available to permit bypassing of the scrubbers when more than three scrubbers require servicing.

The scrubbers are the hydrosonic aspirator type in which draft is induced by scrubbing water that flashes into steam as it mixes with hot flue gases at the scrubber orifice. Flue gases enter the scrubber at temperatures between 480° and 650°C. The scrubbers use water at the rate of 4540 ℓ/min; of this, 1140 ℓ/min are evaporated and 3400 ℓ/min are recycled. Used scrubbing water passes from the scrubber into a mixing tank where lime slurry is added for pH control. The lime treatment system has duplicate lime pumps and piping because of their propensity for plugging. Scrubbing liquor passes from the lime-mixing tank into clarifiers, where particulate matter settles as sludge. Sludge is dewatered by vacuum filtration.

Lime additions to the scrubbing water are controlled automatically by pH instrumentation, because of frequent variations in the composition of furnace exhaust gases. Without proper pH control, sulfur oxides from combustion of the fossil fuels can combine with the scrubbing liquor to form acids that can reduce liquor pH to as low as 2.0. During periods immediately following addition of limestone flux to the furnaces, scrubbing liquor pH remains high without lime additions.

Materials of construction for the scrubber system include carbon steel for the scrubber vessel, 316L stainless steel for the scrubbing water atomizers, and fiberglass-reinforced plastic (FRP) for troughs used to collect the scrubbing liquor. The FRP resin is a phenolic type that can withstand temperatures up to 200°C, although the temperature of the liquor is usually about 70°C. Lime slurry vessels and piping are also constructed from FRP, except for the piping near the slurry pumps, which is stainless steel. The pump casings are rubber-lined cast iron.

MALFUNCTIONS DUE TO CORROSION

Corrosion failures have plagued various components in the scrubbing water treatment system since 4 months after the scrubber system startup. These failures not only have required numerous short-term shutdowns of the scrubbers to facilitate repairs, but also have caused one or both of the operating furnaces to emit uncontrolled exhausts through the bypass stacks.

Corrosion first appeared in the sludge dewatering vacuum blowers at the water treatment plant. The mild steel casings for these blowers deteriorated so quickly that temporary jacketing and patching had to be welded to the blowers several times before replacement casings could be obtained. The replacement casings were constructed of rubber-lined steel.

The next corrosion failures were the lime slurry pumps. These pumps alternately corroded during periods of low pH and plugged during periods of high pH. Problems were so severe on several occasions that duplicate standby pumps failed before the primary pumps could be serviced. These pumps have been replaced with pumps that have rubber-lined casings, but the linings have been only moderately successful because of abrasion damage.

Other corrosion failures have occurred in the piping in the scrubbing water treatment system. Mild steel pipes and fittings were installed by the contractor at some locations instead of specified stainless steel fittings. These components have failed and have been replaced by components made of the specified corrosion-resistant materials.

There have been no serious corrosion problems in the carbon steel scrubber vessel or in any of the FRP components.

DESIGN EVALUATION

Corrosion problems occurred in the Source 8 scrubber system primarily because of difficulty in controlling the pH of the scrubbing liquor. A contributing cause of corrosion was the use of inappropriate materials in locations subjected to intermittent (albeit unexpected) acid conditions. Corrosion problems are likely to be less frequent in the future because maintenance personnel devote more effort to monitoring the pH control system than when the scrubbers were first installed and because unsuccessful materials have been replaced with more expensive corrosion-resistant materials.

Although the pH control circuitry is quite reliable, the pH probes do not remain calibrated for very long. Plant engineers describe the pH probes as the "weakest link" in the scrubbing system. Since installation of the scrubbers, plant engineers have experimented with several probe types, and have tested ultrasonic probe-cleaning methods. These efforts have produced only minor improvements in pH system reliability, so it is still necessary to analyze grab samples of scrubbing liquor in the mill laboratory at least once per shift to verify the calibration of the pH probes.

Compounding the pH control problem is the 5-min detention time in the lime-mixing tank. Variations in scrubbing liquor pH would be dampened if a larger tank could be used, but there is insufficient room near the scrubbers to enlarge the tank by the required amount.

CORROSION-RELATED EMISSIONS AND COSTS

Corrosion failures in scrubbing system components have required that the scrubbers be bypassed on numerous occasions during the first year of scrubber operation. Bypassing has occurred at least 20 times for periods up to 24 h in length because of failures in the sludge dewatering vacuum blowers, lime slurry pumps, and piping. During each emissions episode, Source 8 reported the nature and magnitude of the problems to the State enforcement agency.

Uncontrolled particulate emissions at the mill are estimated to be 23 Mg/day. When operating, the scrubbers remove more than 99 percent of the particulates from the furnace exhausts, reducing mill emissions to 20 percent of the allowable rate. Excess emissions caused by bypassing the scrubbing system were, therefore, in the range of 450 Mg during the first year of scrubber operation.

Corrosion problems in the scrubbers increased plant operating costs by about 10 percent during the first year of scrubber operation. The costs of replacing corroded pumps, vacuum blowers, and piping were more than $50,000 in materials and $20,000 in labor. The original capital investment in the scrubber systems was more than $3 million, but these expenditures will be partially recovered by reductions in refractory maintenance and by increases in furnace capacities made possible by the scrubbers.

SOURCE 9

FABRIC FILTER SERVING PORTLAND CEMENT PLANT

SUMMARY

This facility produces portland cement in a rotary kiln fired with high-sulfur coal. Exhausts from the kiln pass through a set of multiclones, several radiant cooling loops, and a reverse-air fabric filter. Within the first year of filter operation, the rate of filter bag failures due to corrosion of support rings and bag hangers became excessive. Changing the materials in the support rings and changing the design of the hangers increased the life of these components to acceptable levels. Corrosion has also attacked portions of the filter enclosure. Corrosion of the bag hardware and the filter enclosure has resulted because of acid condensation within the filter and rainwater inleakage into the filter.

During the first year of filter operation, the corrosion failures undoubtedly increased the particulate emissions above regulatory limits on several occasions. The cost of repairing the corroded parts was in excess of $24,000, but it was shared by Source 9 and the filter manufacturer.

SOURCE DESCRIPTION

Source 9 produces about 250,000 Mg per year of portland cement in a single, dry process kiln. The kiln is fired with 2½ percent sulfur coal and runs continuously for campaigns lasting up to 4 months. The kiln is shut down three to four times a year for repair of the refractory lining and five to six times a year (briefly, for less than 8 hours) for unexpected maintenance.

Exhaust gases from the kiln pass first through a set of multiclones for removal of large particulates, then through a set of four radiant cooling loops, and finally through the fabric filter (Figure A9-1). The old stack (available for emergency bypass) and the system fan are between the cooling loops and the filter. The cooling loops reduce filter inlet gas temperatures to between 230° and 260°C.

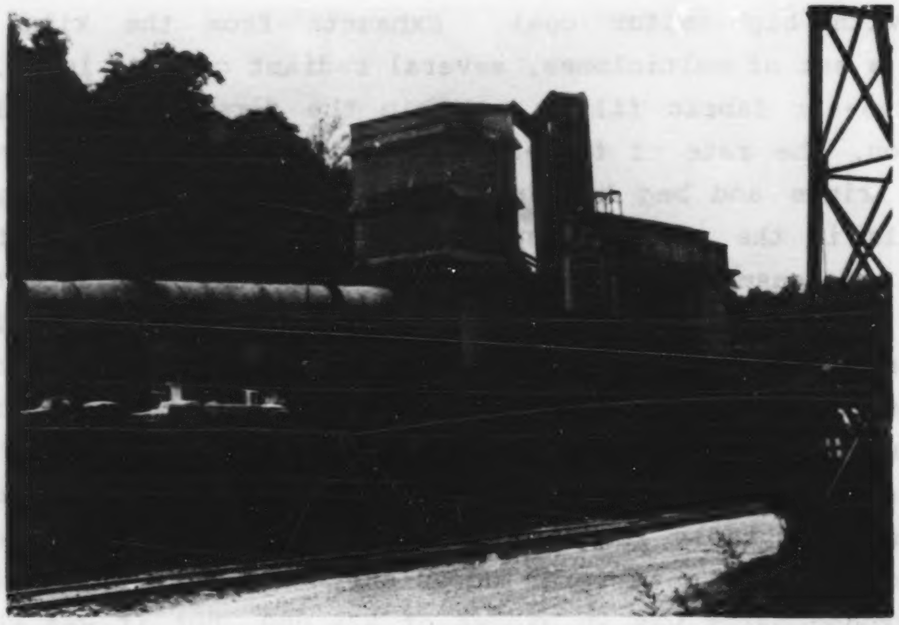


Figure A9-1. View of Source 9 with rotary kiln on the left, fabric filter on the right, radiant cooling in the center, and emergency bypass stack (partially obscured) behind the cooling loops.

The reverse-air fabric filter has 10 compartments and a roof monitor exhaust. The filter is about 4 years old; it is constructed of mild steel, and the interior steel surfaces were originally coated with paint (type unknown). All outside walls of the filter except the entry hatches are thermally insulated. The fiberglass filter bags have wire rings sewn into the fabric for preventing bag collapse; these rings, originally constructed of mild steel, are now cadmium-coated steel. The filter system instrumentation includes a manometer in each compartment, a manometer across the entire filter with an indicator in the control room, a filter thermocouple, fan ammeters, a fan tachometer, and reverse-air fan malfunction warning lights. The thermocouple is linked to a warning light and to an alarm to indicate high-temperature excursions that could damage the filter bags.

MALFUNCTIONS DUE TO CORROSION

Bag Support Rings and Hangers

Within 1 year of fabric filter startup, bag failures had become frequent because of rapid corrosion of the mild steel bag support rings (Figure A9-2). Broken rings not only allowed the bags to flex but also provided sharp points that induced punctures and tears in the fiberglass fabric. A second cause contributing to bag failure was corrosion of the bag support springs. Support spring failures reduced the bag tension, interfered with the cleaning of the fabric, and occasionally allowed the bags to fall into the filter hoppers.

Both of the above corrosion problems were alleviated by changing the materials of construction. All replacement filter bags have cadmium-coated steel rings rather than the plain steel rings. The bag support mechanisms were redesigned so that a heavy chain-type hanger replaced the light spring-type hanger. The manufacturer was helpful in correcting these materials problems and shared some of the expenses attributed to ring and hanger failures.

Structural Steel

The structural steel showed signs of corrosion during the inspection, but there have been no structural failures to date. The corrosion was most apparent near the roof exhaust (Figure A9-3) and near the access doors where heat losses and condensation are most likely (Figure A9-4). In general, the structural

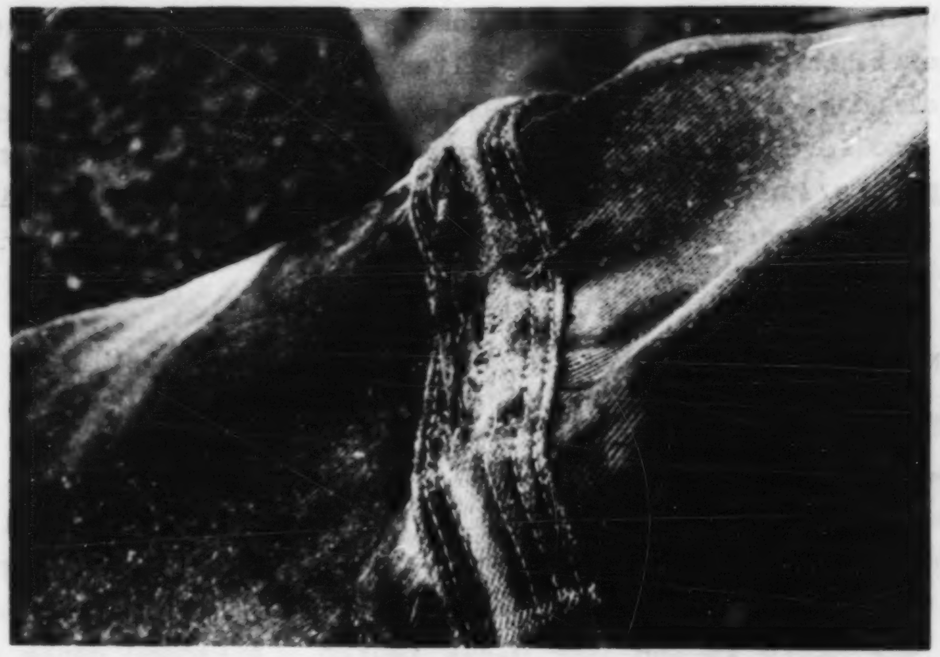


Figure A9-2. Filter bag showing tear caused by abrasion with corroded, mild steel support ring.

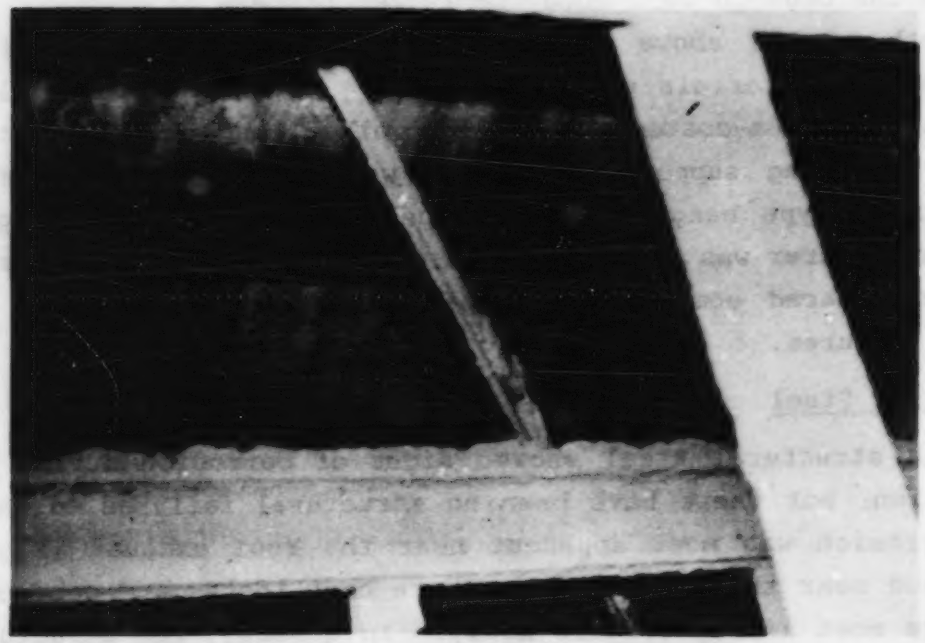


Figure A9-3. Structured steel near filter showing corrosion of the roof support beam.

corrosion did not appear to pose a serious problem; however, repair of corroded members, especially near the access doors, will be required during the life of the filter. An undetermined type of paint visible on the structural steel within the filter had protected the steel during the first 4 years of filter operation (Figure A9-5). Much of this coating, however, had failed by the time of inspection, exposing the steel to the kiln exhaust gases.

Other Filter System Components

The plant did not report any serious corrosion problems in the fan, cooling loops, ductwork, or any other components.

DESIGN EVALUATION

Combustion of coal that contains 2½ percent sulfur creates the potential for corrosion in any downstream equipment for handling flue gas. To minimize corrosion caused by acid condensation in a dry particulate collection system, it is highly desirable to maintain temperatures above the sulfuric acid dewpoint and to prevent moisture inleakage. It is apparent that some amount of acid condensation does occur within the Source 9 fabric filter. It is also possible that rainwater occasionally enters the filter at the roof monitor exhaust and at the entry hatches.

Evidence of corrosion is most apparent in the relatively cooler areas near the filter access doors and roof and less apparent on the interior structural steel. Corrosion in both locations is limited somewhat by the formation of a cement-like cake on exposed steel structures. Portland cement is known to inhibit corrosion of mild steel in most environments.[1] The severity of the corrosion in the mild steel bag rings and hangers may have resulted because no cement cake formed on these components. Contact with the fabric probably abraded the ring surfaces clean, and the hangers probably remained clean because they were on the clean side of the filter.

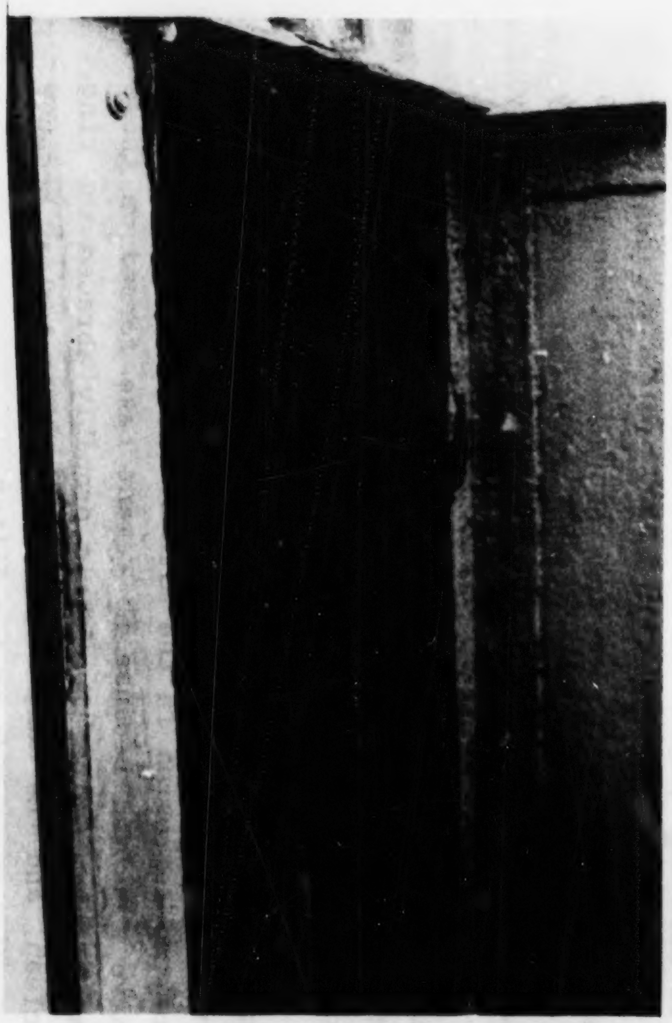


Figure A9-4. Mild steel fabric filter enclosure showing corrosion near the uninsulated hatch. The corrosion pattern in the upper left corner of the hatch frame is due to condensation of acid from warm flue gases leaking through the hatch seal.

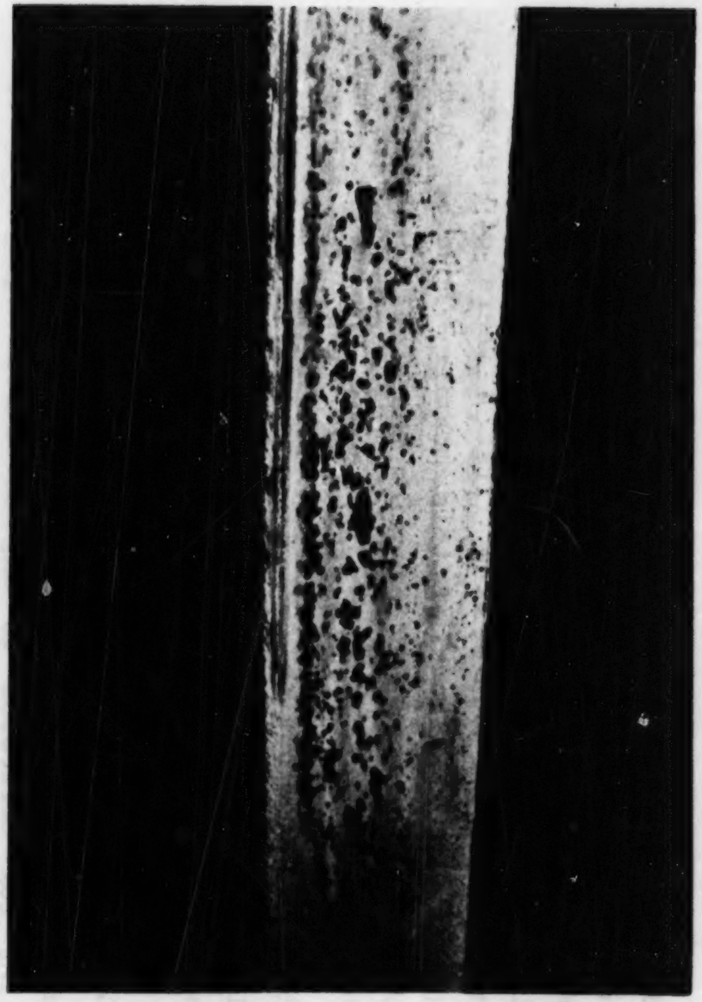


Figure A9-5. Mild steel structural support showing the remnants of the original protective coating.

Replacement of the plain steel rings with cadmium-coated ones seems to be an appropriate design change, as the coated ones are providing much longer service than the plain rings. The use of heavier chain-type hangers also seems appropriate; their heavier gauge construction will provide longer service than the lighter springs before failing from corrosion. It might also be helpful to check the filter enclosure for leaks; several places were observed in the roof and near the entry hatches during the filter inspection that might allow entry of rainwater.

CORROSION-RELATED EMISSIONS AND COST

During the first year of filter operation, there were undoubtedly excursions above the emission limits because of numerous bag failures. Plant personnel, however, were not able to quantify the frequency, duration, or severity of these excursions. Plant personnel described deviations above regulatory emission limits as infrequent during the first year of filter operation and as especially rare since the filter bag rings and hangers have been redesigned.

The costs of the corrosion failures have been limited to those for replacing all filter bags after only 1 year of service plus those for changing the hanger designs. The filter manufacturer assumed some of the financial burden associated with these changes. The plant reported that a set of new bags costs about $24,000. The total capital investment for the filter was about $1 million.

REFERENCE

1. Hamner, N. E. Coatings for Corrosion Protection, Chapter 14, NACE Basic Corrosion Course. National Association of Corrosion Engineers, Houston, Texas, 1977.

SOURCE 10

ELECTROSTATIC PRECIPITATOR SERVING PORTLAND CEMENT PLANT

SUMMARY

This wet process portland cement plant has a four-chamber electrostatic precipitator (ESP) for control of particulate emissions from the rotary kiln. During the first 8 years of operation, several ESP components have failed as a result of acid dewpoint corrosion. These failures have been repairable, but it is expected that a major reconstruction of the ESP will soon be required. The designed life of the control system is 30 years.

The potential for corrosion is inherent in an ESP serving a wet process kiln, especially when coal is used as fuel. Corrosion could probably be prevented by maintaining higher kiln exhaust temperatures or by switching to sulfur-free fuels, but a substantial penalty in fuel costs would be paid.

The source reported no major incidents of excess emissions attributable to corrosion in the ESP. The costs of the corrosion have been substantial, however, and will undoubtedly increase as additional ESP components require replacement.

SOURCE DESCRIPTION

Source 10 is a wet process portland cement plant with a single, coal-fired kiln. Kiln exhausts pass through a four compartment ESP for particulate removal. Gas flow through the ESP is approximately 190 m^3/s. Draft in the system is induced by a fan located between the ESP exhaust and the 90-m plant stack. Most plant equipment is 8 years old and represents state of the art technology. The plant stack is the major remnant of a previous cement plant that was scrapped in order to build the present more modern plant.

The kiln operates continuously for campaigns averaging 3 months in length. Chains have been attached to the inside of the kiln to improve transfer of heat to the product. These chains enable the kiln to operate using less fuel and, consequently, the kiln exhaust temperature is lower than it would be without the chains. The backend product temperature averages about 540°C, and the exhaust gas at the ESP inlet is 230°C. The outlet temperature of the ESP (in the breeching at the stack) averages 145°C. Because the ESP is well insulated, the ESP exhaust gas temperatures vary no more than 30°C between the extremes of summer and winter.

Space constraints imposed by the location of the existing stack required that the four ESP chambers be stacked in pairs (Figure A10-1). Gas flow from the kiln divides into four parallel streams, each passing through an individual chamber. Adjoining chambers share dust hoppers and screw conveyors. The plant performs detailed maintenance on all ESP components twice a year while the kiln is out of service for rebuilding of the refractory.

The ESP chambers are constructed of 5-mm thick mild steel, and the inside surfaces are uncoated. Structural support is provided by box type steel beams (Figure A10-2). Because the plant uses the wet process and is located in a cold climate, the ESP chambers and hoppers are well insulated. The mild steel ductwork is not insulated and there are no hopper heaters. The collection plates are also mild steel and are hung in the chambers as indicated in Figure A10-2. The discharge wires are plow steel and the wire weights are cast iron. The kiln stack is concrete with a steel ring at the top.

MALFUNCTIONS DUE TO CORROSION

The first corrosion-related malfunctions were in the secondary circuit insulator compartments. The casings of the

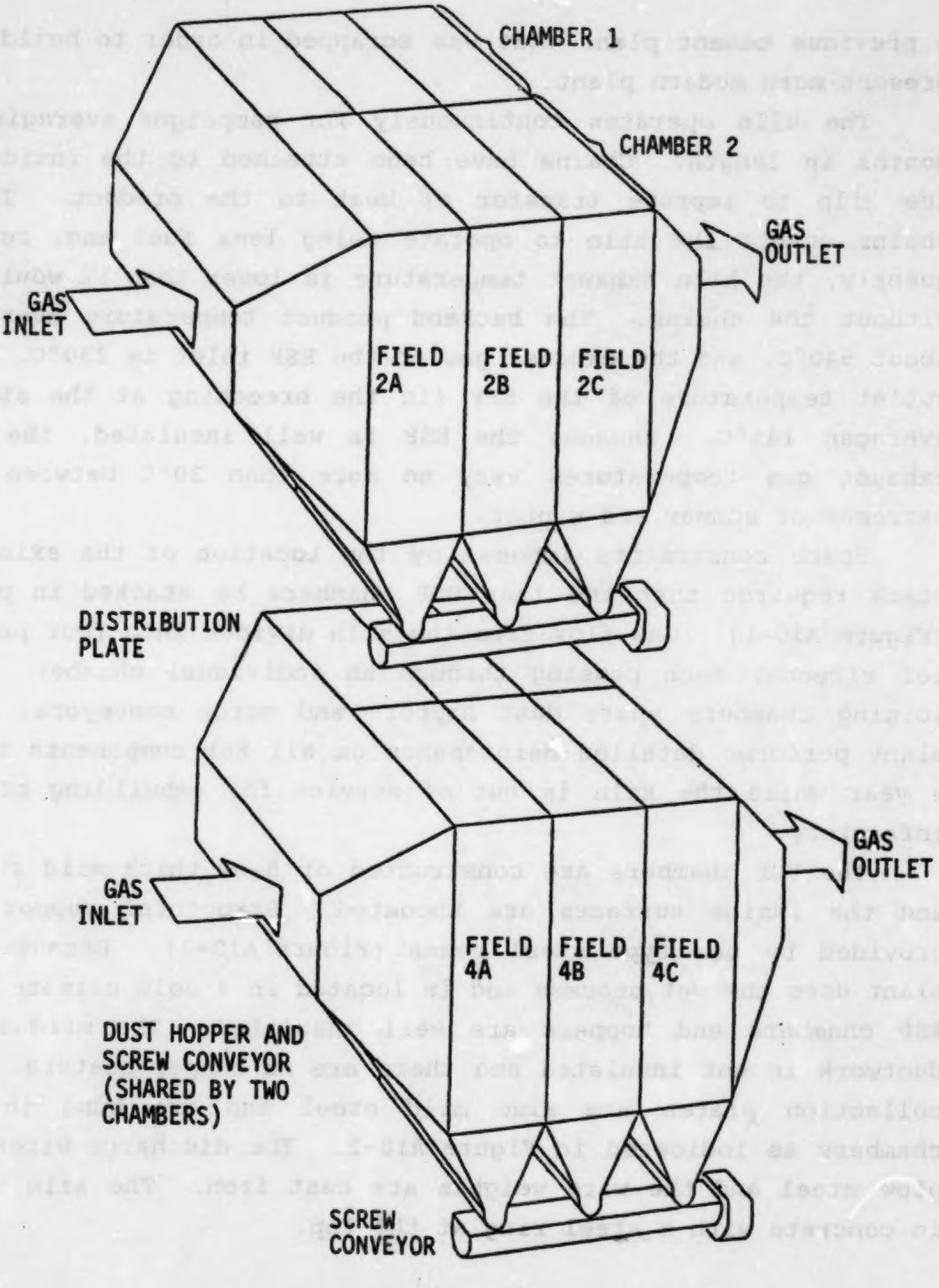
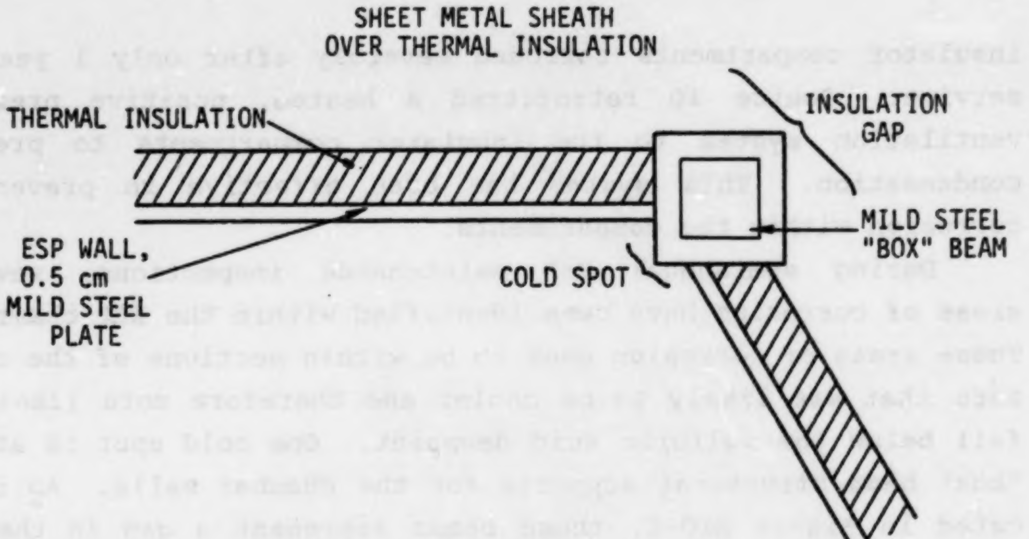

CHAMBER 1
CHAMBER 2
GAS OUTLET
GAS INLET
FIELD 2A
FIELD 2B
FIELD 2C
DISTRIBUTION PLATE
GAS OUTLET
GAS INLET
FIELD 4A
FIELD 4B
FIELD 4C
DUST HOPPER AND SCREW CONVEYOR (SHARED BY TWO CHAMBERS)
SCREW CONVEYOR

Figure A10-1. General arrangement of Source 10 ESP.


SHEET METAL SHEATH
OVER THERMAL INSULATION
INSULATION
GAP
THERMAL INSULATION
MILD STEEL
"BOX" BEAM
ESP WALL,
0.5 cm
MILD STEEL
PLATE
COLD SPOT

"BOX" BEAM CONFIGURATION

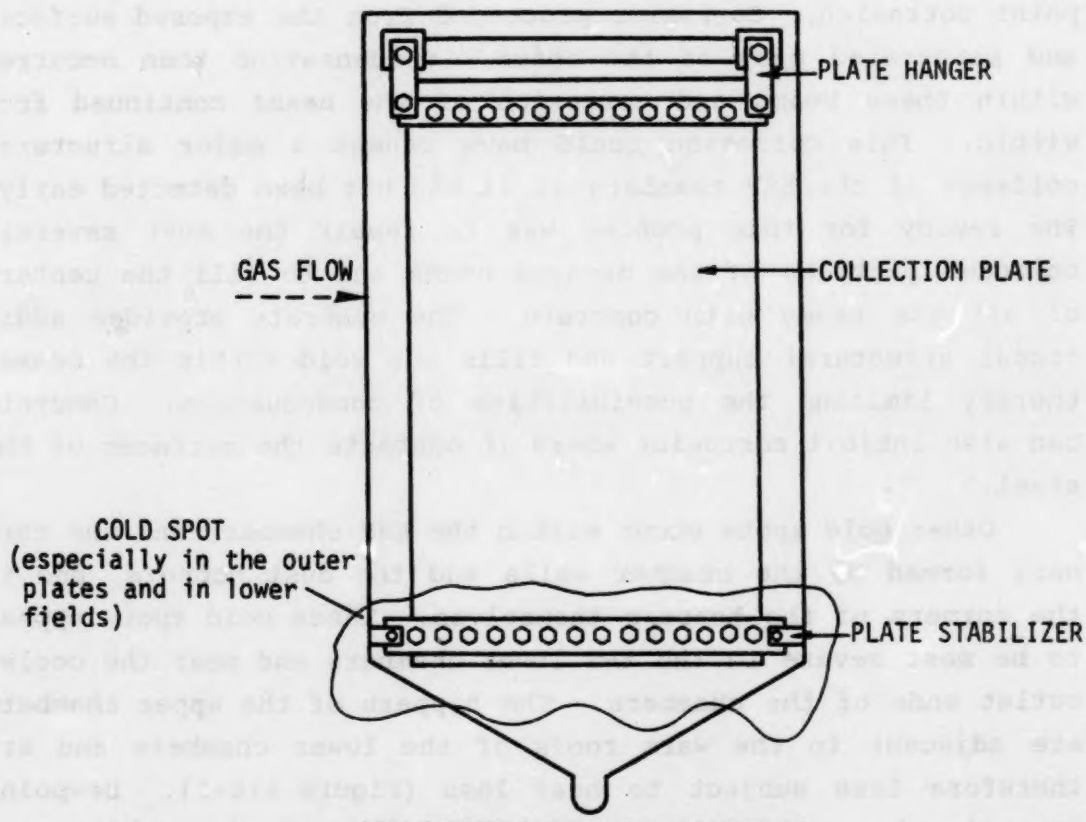


PLATE HANGER
GAS FLOW
COLLECTION PLATE
COLD SPOT
(especially in the outer
plates and in lower
fields)
PLATE STABILIZER

COLLECTION PLATE HANGING METHOD

Figure A10-2. Locations of cold spots within the Source 10 ESP.

insulator compartments corroded severely after only 1 year of service. Source 10 retrofitted a heated, positive pressure ventilation system to the insulator compartments to prevent condensation. This system has been effective in preventing corrosion within the compartments.

During semiannual ESP maintenance inspections, several areas of corrosion have been identified within the ESP chambers. These areas of corrosion seem to be within sections of the chambers that are likely to be cooler and therefore more likely to fall below the sulfuric acid dewpoint. One cold spot is at the "box" beam structural supports for the chamber walls. As indicated in Figure A10-2, these beams represent a gap in the ESP chamber thermal insulation. Beam surfaces exposed to the sulfur-bearing flue gases have consequently suffered severe dewpoint corrosion. Corrosion proceeded from the exposed surfaces and penetrated many of the beams. Condensation then occurred within these beams and corrosion of the beams continued from within. This corrosion could have caused a major structural collapse of the ESP chambers if it had not been detected early. The remedy for this problem was to repair the most severely corroded portions of the damaged beams and to fill the centers of all the beams with concrete. The concrete provides additional structural support and fills the void within the beams, thereby limiting the possibilities of condensation. Concrete can also inhibit corrosion where it contacts the surfaces of the steel.[1]

Other cold spots occur within the ESP chamber near the corners formed by the chamber walls and the dust hoppers, and in the corners of the hoppers themselves. These cold spots appear to be most severe in the two lower chambers and near the cooler outlet ends of the chambers. The hoppers of the upper chambers are adjacent to the warm roofs of the lower chambers and are therefore less subject to heat loss (Figure A10-1). Dewpoint corrosion has occurred at several points near the cold spots. Corrosion has occurred in both the ESP walls and in the hopper walls. Damage to these walls, although troublesome, can be repaired by patching during regular maintenance. Cold spots, however, extend into the lower reaches of the ESP chambers causing corrosion at the bottoms of the ESP plates (Figure A10-2). This has resulted in significant corrosion of the plate structures, especially at the crevices formed where the stabilizer bar is bolted to the plates. Several plates have corroded completely away from the stabilizers. These unfastened plates can contact discharge electrodes, taking a field out of service. Replacement of the plates is a much more difficult and expensive operation than the patching of the chamber walls described above.

In addition to corrosion in the ESP chambers, there has been corrosion at three other locations in the kiln flue gas treatment system. Corrosion has occurred in the stack sampling ports, the steel ring at the top of the stack, and in the ductwork from the fan to the stack. Each of these components has required repair or replacement during the first 8 years of plant operation.

DESIGN EVALUATION

The use of coal to fire the Source 10 kiln adds significant amounts of sulfur oxides to the exhaust gases, and the use of the wet process in the blending of the raw materials adds significant amounts of water vapor to the exhaust gases. Under these circumstances, acid condensation and subsequent corrosion can be avoided only by consistently maintaining exhaust gas temperatures above the acid dewpoint.

Source 10 has attempted to maintain high temperatures in the ESP through the use of extensive thermal insulation. This strategy has been successful at most locations within the ESP, but it has not worked at the more exposed extremities of the chambers and hoppers. In addition, the tail-end components such as ducting near the stack, the stack sampling ports, and the stack ring also seem to be subject to acid condensation.

Several options are available for dealing with the acid condensation problem at Source 10. One option would be to convert the plant from the wet process to the dry process. This option would reduce the water vapor in kiln exhausts, thereby lowering the acid dewpoint temperature. Disadvantages of this option are the considerable capital expenditures involved in converting raw materials blending facilities, the possible detrimental effects the conversion might have on production rates or

product quality, and the adverse effects the change may have on the particle resistivity and collectability in the ESP.[2]

A second option is to switch from coal to natural gas or low-sulfur fuel oil to decrease the amount of sulfur entering the flue gases. This would also lower the acid dewpoint temperature. Disadvantages of this option include higher fuel prices and possible supply interruptions.

A third option is to fire the kiln at a higher temperature so that exhaust gases enter the ESP at higher temperatures. The obvious disadvantage of this option is the increase in fuel use. A study of temperature variations within the ESP would be helpful prior to implementation of this option so that the minimum required temperature increased can be defined.

A final option is to simply continue present operating practices and to replace the ESP components as they fail. Source 10 anticipates that a major rebuilding of the ESP will be required after about 10 years of service because of corrosion (design life for plant equipment is 30 years). Where feasible, rebuilt ESP components should be constructed of materials more resistant to sulfuric acid.

The ultimate choice among the above options will require economic analysis as well as consideration of the technical merits for each option.

CORROSION-RELATED EMISSIONS AND COSTS

No specific incidents of excess emissions are attributable to corrosion in the ESP. Corrosion damage has not yet caused catastrophic failure of the ESP system. Damage to the ESP has been repaired during periods when the kiln is out of service.

The costs of the corrosion have been substantial. The total installed cost of the ESP was approximately $800,000 (1970 dollars) and the auxiliary equipment such as pilings, noise barriers, rotary air locks, screw conveyors, insulator compartment blowers, etc. cost more than $1 million (1970 dollars). It is expected that most of the ESP components and some of the auxiliary components will require major repair or replacement after only 10 years of the 30-year design life.

REFERENCES

1. Hamner, N. E. Coatings for Corrosion Protection, Chapter 14, NACE Basic Corrosion Course. National Association of Corrosion Engineers, Houston, Texas, 1977.

2. Kulujian, N. J. Inspection Manual for the Enforcement of New Source Performance Standards: Portland Cement Plants. EPA 340/1-75-001, September 1975.

SOURCE 11

FABRIC FILTERS SERVING SLAG CUPOLAS

SUMMARY

This plant includes two slag cupolas that are controlled for particulate emissions by fabric filters. During the first 3 years of operation, severe degradation has occurred in the filtering medium and also moderate corrosion in the mild steel filter enclosure. The causes of these material failures have been a lack of adequate flue gas temperature control within the filter and the presence of sulfur oxides, water vapor, and traces of fluorides in the raw materials.

A manually controlled dilution air cooling system has allowed cupola flue gas temperatures to vary widely. During the initial years of operation, the filters apparently operated below the sulfuric acid dewpoint a significant fraction of the time. These moist conditions led to the destruction of the fiberglass bags and to corrosion of the mild steel filter enclosures. The presence of unexpected traces of fluorides in the flue gas probably accelerated the degradation of the fiberglass. Source 11 replaced the fiberglass bags with polyester bags that were subsequently destroyed by a high-temperature excursion. Additional high-temperature excursions have been prevented by installing high-temperature alarms in each filter. The acid condensation problem has not been completely solved, but the severity of acid condensation has been decreased by operating the cupolas with slightly less dilution air added to the flue gases. Fluorides have been virtually eliminated by careful selection of slag feedstocks for the plant.

SOURCE DESCRIPTION

Source 11 consists of two mineral wool cupola lines, each containing a slag cupola, a mineral wool spinner, a packaging line, and a fabric filter for treating the cupola exhausts. Both cupola lines are designed to operate 24 h/day, but during the first 3 years of operation market conditions have not permitted full operation. In addition, production has been interrupted periodically by a variety of production line or fabric filter malfunctions. The actual operating schedule during the first years of operation has been characterized by numerous cold startups. At the present time, market conditions are improved and most production problems have been solved; thus the cupola lines are approaching their designed continuous operation.

Each cupola is a water-cooled steel cylinder with a charging door near the top, a trap door type bottom, and a slag pit beneath the cylinder bottom. Combustion air is provided by tuyeres around the lower portion of the cupola, and dilution air for flue gas cooling enters through the charging door and through a damper on top of the cupola. Flue gases exit the cupola through a duct that leads to the fabric filter.

After startup, each cupola is charged at approximately 20-minute intervals. Raw materials for the cupolas include steel-mill and copper-smelter slags as well as metallurgical coke fuel. Cupola exhausts contain a mixture of fly ash, soot, and sulfur compounds, which can vary in chemical composition as raw materials vary. Sulfur compounds originate from the combustion of the coke as well as from the melting of some of the slags. The steel slags typically contain 1.3 percent sulfur, and the copper slags contain negligible amounts of sulfur. Copper slags, however, can contain as much as 1 percent lead as well as traces of fluorides.

During the first years of operation, both copper slag and steel slag were used. Determining factors in their use were relative costs, availability, and the quality of mineral wool they produced. More recently the copper slag has not been used in an attempt to reduce the exposure of workers to lead and to reduce the amount of fluorides entering the fabric filter.

Exhaust gas temperatures typically ranged between 55°C after a charge to 105°C just prior to a charge, during the first years of operation. Later, the source improved exhaust gas temperature regulation (through more careful operation of the cupola and the dilution air damper) so that exhaust gas temperatures typically ranged between 70° and 165°C. During most of this early period of operation, however, the cupolas were subject to an unknown number of temperature runaways. This problem has only recently been corrected by the use of high-temperature alarms that give the operators sufficient time to control unusually high exhaust gas temperatures.

Each fabric filter contains four compartments and is equipped with both reverse-air and shaking modes of cleaning. The filters are also designed so that individual compartments may be isolated with dampers to allow for on-line repair. The filter shells are made of carbon steel with no coating on the inside. The filter walls and roof are thermally insulated. The original filter bags were fiberglass, but Source 11 has replaced these with polyester bags. Gas flow through the filters is induced by fans located between the filters and the stacks.

MALFUNCTIONS DUE TO CORROSION

During the first 3 years of operation, several components of the filters have failed because of materials breakdown. The most troublesome of these failures have been repeated failures of the bag fabric. Fiberglass fabric was originally chosen because of the expected high temperatures. Fiberglass bags, however, failed within a few months of service. The failure of the fiberglass bags appeared to be the result of self-abrasion of the fibers during the shaker cleaning mode. Subsequent chemical analysis of the cupola raw materials revealed traces of fluorides in the slags, which probably played a significant role in the degradation of the fiberglass material. The replacement polyester bags also failed once, because of a high temperature excursion.

Other materials problems in the filter have included corrosion of copper tubing serving the filter magnehelic gauges and general corrosion of the carbon steel shells. This latter problem has not yet resulted in any component failures, but if permitted to continue, it may threaten the structural integrity of the filters.

DESIGN EVALUATION

The principal design deficiency in the filter systems is the inability to maintain cupola exhaust gas temperatures below the maximum safe level for the filter fabric, but above the sulfuric acid dewpoint. Exhaust gases are cooled by dilution air, but the dilution air dampers do not automatically respond to process changes. Typical practice has been to set the damper positions so that exhaust gases are cooled safely below the upper temperature limit of the fabric. This can allow exhaust gas temperatures to fall below the acid dewpoint during cupola startup or immediately after cupola chargings.

Failure of the fiberglass bags probably resulted from the effects of condensed moisture and from the presence of fluorides in the exhaust gases. Fiberglass fabric has a tendency to self-abrade when flexed under moist conditions and its fibers are weakened when both fluorides and moisture are present.[1]

After the first set of polyester filter bags were destroyed by fire, Source 11 installed temperature alarms in the filters to warn of high-temperature excursions. Since installation of these alarms, there has been no further high-temperature damage to the bags. Source 11 has not altered the filter systems in any way to assure that flue gas temperatures remain above the dewpoint. Automatic thermocouple-controlled dampers would probably improve control of low temperatures. This could reduce the condensation of water and sulfuric acid and thereby reduce degradation of the mild steel filter enclosures, as well as the bag fabric and the copper magnehelic gauge tubing.

An additional factor contributing to internal moisture in one filter enclosure was poor welding. Inspection of the inside of this filter revealed a gap in one of the welded seams at the roof of one compartment. This gap allowed cool ambient air and rainwater to be drawn into the filter by the induced draft.

CORROSION-RELATED EMISSIONS AND COSTS

Source 11 maintains no records that would allow a quantification of either excess emissions or costs resulting from materials failures. Excess emissions caused by materials failures have consisted of substantially decreased particulate collection efficiency because of to bag failures. The number and duration of these episodes cannot be determined, nor can the emissions rate during these episodes. Costs accrued because of filter system material failures have included labor costs and materials costs associated with replacing the bag sets several times, the costs of lost production because of shutdowns required during repair of the filters, and the costs of a decrease in the useful life of the filter enclosures.

REFERENCE

1. Strauss, W. Industrial Gas Cleaning, second edition. Pergamon Press, New York, 1975, p. 298.

SOURCE 12

FABRIC FILTER SERVING GAS-FIRED AGGREGATE ROTARY DRYER

SUMMARY

This facility operates a gas-fired rotary dryer as part of a process to prepare steel-mill slag for use in the glass industry. Exhausts from the dryer were originally treated for particulate removal by a reverse-air, shaker-type fabric filter. After approximately 1 year of service, the filter was retired because of severe corrosion and chronic plugging. The filter was replaced by a venturi scrubber, which has given good service for about 1 year. The apparent cause of the filter corrosion and plugging was water and acid condensation. Condensation occurred because ductwork from the dryer to the filter was quite long and exposed to ambient air. The average January temperature at the plant site is approximately 0°C, and temperatures of -15°C are not uncommon during the winter.

SOURCE DESCRIPTION

Source 12 purchases blast furnace slag from a neighboring steel mill and crushes it to specifications for use as a raw material in manufacturing glass. Wet slag is received in rail cars directly from the steel mill slag pit. Wet chunks of slag are fed into the rotary dryer countercurrent to the direction of gas flow. A natural gas-fired burner supplies heat to the dryer. The dryer has the capability to use No. 2 fuel oil in lieu of natural gas, but natural gas has generally been available more than 99 percent of the time. The drying process generates a large quantity of dust that is separated from the dryer exhaust gases by the particulate control system. Dried slag is segregated according to size and crushed in a series of crushers, using a Stedman mill. The slag is crushed to a 16-mesh size and is sold as a feed stock for glass production. The plant operates one or two shifts a day, depending on the market for its product.

The first particulate control system at the plant was a fabric filter that used both reverse-air and shaking mechanisms for cleaning the fabric. Draft for the system was provided by a fan between the dryer exhaust and the filter. The filter was installed in an unused area of a building adjacent to the dryer, a location that required a very long outdoor duct between the fan and the filter. The filter was designed for an inlet temperature of 70°C. After a short period of operation, it became apparent that dryer exhausts were being cooled to below the acid dewpoint during transit through the duct; thus, a modest layer of insulation was placed around the duct.

The fabric filter was eventually rendered inoperative by corrosion and plugging, and was replaced by the present scrubber system. The scrubber system consists of a venturi and a cyclonic mist eliminator. Because the scrubber is located adjacent to the dryer and the fan, considerably less ductwork is required than for the fabric filter system. Scrubbing water for the system is recirculated, and system blowdown is clarified in settling ponds. There is presently no pH control or other chemical treatment for scrubbing water. Both the venturi and the mist eliminator are constructed of mild steel, but there have been no corrosion failures during their first year of operation.

MALFUNCTIONS DUE TO CORROSION

Corrosion first became evident in the fabric filter system less than 3 months after startup. At this time, the interior structures of the filter were hand-brushed and coated with zinc-chromate paint. The paint was not effective because of the difficulty of properly preparing the filter surfaces prior to application of the paint. Problems continued throughout the first year of filter operation as a result of moisture condensation within the filter. Corrosion attacked all steel structures within the filter and also portions of the ductwork between the dryer fan and the filter. Insulation was placed around the ductwork in an attempt to control temperatures within the filter, but gas temperatures apparently continued to fall below the dewpoint. Within 1 year of startup, the filter had failed completely because of corrosion and bag-blinding problems.

DESIGN EVALUATION

Process Characteristics

The corrosion in the fabric filter resulted because the flue gas temperatures fell below the sulfuric acid dewpoint. Coke used in the steel mill added sulfur to the slag, and cooling water at the mill slag pit added moisture. The sulfur and moisture were driven off during the drying process and condensed as sulfuric acid within the filter. Attempts to prevent this condensation by insulating the ductwork failed because the modest layer of insulation was not sufficient to maintain high gas temperatures in such a long duct. In addition, some of the insulation had broken away from the duct after a year of service.

Materials of Construction

The fabric filter structural parts and the associated ductwork were made of mild steel, which is a poor choice for acid mist service. Materials resistant to acid conditions, however, would have been prohibitively expensive compared with other design changes that would have prevented condensation.

The zinc-chromate coating applied to the fiter was not totally inappropriate for the conditions in the system. The field application over a hand-brushed surface, however, did not produce a high-quality coating. Had the coating been applied in the shop over a sandblasted surface, it may have provided partial protection from corrosion.

Equipment Arrangement

The configuration of the equipment was the primary reason for acid dewpoint troubles in the fabric filter. If the filter had been constructed nearer the dryer and if the filter enclosure and the ductwork had been well-insluated, acid dewpoint problems may have been prevented. The equipment manufacturer was unable to foresee the acid dewpoint problems and was unable to find a solution to the problems when they appeared.

CORROSION-RELATED EMISSIONS AND COSTS

The fabric filter system was so unreliable as a result of corrosion and plugging that emissions were well above regulatory limits during much of the year it was in operation. The local enforcement agency permitted the source to operate without particulate controls whenever the filter system was malfunctioning. The cost of the abandoned filter system was in excess of $30,000. The source spent undetermined amounts for unscheduled maintenance and repair work to the filter and for the scrubber system that replaced the fabric filter.

SOURCE 13

WET SCRUBBER SERVING ROTARY LIME KILN

SUMMARY

This plant is an 11-year old rotary lime kiln that has had a succession of exhaust gas particulate control systems. The first particulate control system was a relatively ineffective settling chamber. Under pressure from the State Agency, multiple cyclones were added in series with the settling chamber. These multiple cyclones improved particulate control considerably, but emissions still remained above regulatory limits. The plant then installed a carbon steel wet scrubber which met the regulatory limits, but that failed because of corrosion during the first year of operation.

Corrosion of the carbon steel scrubber was caused by the presence of sulfur oxides and nitrogen oxides in the kiln exhausts which formed sulfuric and nitric acids in the scrubbing liquors. Corrosion affected the scrubber but not the quench chamber because the bulk of the alkaline components in the flue gases are removed in the quench chamber. Source 13 eventually replaced most carbon steel scrubber system components with 316L stainless steel components. The 316L alloy is withstanding the corrosive scrubber environment.

Scrubber corrosion increased the particulate emissions considerably during the first year of scrubber operation and was very costly. Corrosion-related excess emissions probably exceeded 20 Mg during this period. Repair and replacement of corrosion-damaged scrubber components cost approximately $300,000 (1978 dollars). In addition, the plant lost between $300,000 and $400,000 in corrosion-related lost production during the first year of scrubber operation.

SOURCE DESCRIPTION

The Source 13 lime facility began production approximately 11 years ago at an existing limestone quarry. The principal component of the facility is the coal-fired rotary kiln, which was moved to its present location from another plant. Other components in the original facility, including a settling chamber for particulate control, were installed new.

Because the settling chamber did not reduce particulate emissions to regulatory limits, Source 13 added a set of multiple cyclones to improve collection efficiency. The multiple cyclones reduced emissions substantially, but emissions continued to exceed the standards. Source 13 then installed a carbon steel wet scrubber system. This scrubber system has recently been replaced with a 316L stainless steel scrubber system of nearly identical design.

The kiln is designed to run continuously for campaigns lasting up to 60 days. Actual campaigns have lasted an average of 20 days, with occasional shutdowns occurring in as few as 7 days. Coal sulfur content typically ranges between 1.0 and 1.25 percent. The kiln, as presently fired, uses significant excess air, because of excessive air inleakage into the kiln.

Kiln exhaust gases exit through refractory brick-lined carbon steel ducting. This ducting leads to the scrubber system quench chamber that is designed to quench exhaust gases having a maximum temperature of 1090°C. The quench chamber water pumps can deliver up to 2270 ℓ/min of water. Actual kiln exhaust temperatures vary between 760° and 870°C, and actual water use is not measured. Typical quench chamber outlet temperatures vary between 90° and 120°C. Because quench water sprayed into the vessel is not completely evaporated, the quench chamber also serves as a spray type precleaner for the venturi scrubber. Approximately 70 percent of the particulate is collected by the unevaporated water droplets in the quench chamber.

Cooled and saturated gases pass from the quench chamber to the venturi scrubber for final particulate removal. The venturi scrubber is designed to operate with a pressure drop of up to 7.5 kPa, and its pumps can deliver up to 760 ℓ/min of water. Actual pressure drop across the venturi averages about 4.5 kPa because of the air inleakage at the kiln. Pressure drop across the venturi is measured by a permanently mounted differential manometer. As in the quench chamber, water use in the venturi scrubber is not measured. Venturi outlet gas temperatures vary between 40° and 65°C.

The venturi scrubber is followed by a cyclonic dropout chamber for collection of entrained water droplets, a 200 hp induced draft fan, and the kiln stack. Each component from the venturi to the kiln stack (including the ductwork) has been replaced with 316L stainless steel. Water in both the quench chamber and the venturi scrubber is once through. Spent slurry from both vessels is combined into one stream and discharged into an unused limestone pit. Combined pump capacity for both vessels is 120 hp.

Gas temperatures in the scrubber system are measured at three locations using thermocouples. Thermocouples at the quench inlet and the quench outlet are connected to high temperature alarms, but the thermocouple at the fan inlet has no alarm. The scrubber system has a bypass damper for emergency use, such as during a loss of water, but it is manually actuated rather than actuated by the temperature alarms.

MALFUNCTIONS DUE TO CORROSION

During the first year of service, there were numerous corrosion failures in the scrubber system. The first failure was in the carbon steel induced draft fan, which failed after only 4 weeks of service. This fan was rebuilt four times during its first 8 months of operation. During one of the earlier rebuilds, the carbon steel fan blades were replaced with 316L stainless steel because the blades seemed to suffer the most severe corrosion. During the final rebuild, all remaining carbon steel fan components were replaced with 316L stainless steel. This new stainless steel fan has provided good service.

Many other scrubber components also failed during the first year of operation. Failures included the venturi, dropout chamber, ductwork, and stack, all of which were originally carbon steel. Failures in these components required frequent patching and occupied the attention of two of the maintenance crew nearly full time for the first year of service. The plant initially patched each failure by welding a carbon steel plate over the affected area, but it was soon apparent that carbon steel was unsuitable anywhere downstream from the quench chamber. The remedy for corrosion in these carbon steel components was eventual replacement with 316L stainless steel.

DESIGN EVALUATION

The present scrubber system at Source 13 represents a significant improvement in particulate collection efficiency compared with the multiple cyclones. When the scrubber system is operating properly, the lime kiln meets applicable particulate emissions regulations. Problems in the scrubber system have been in reliability and have been caused almost exclusively by corrosion.

When the State required Source 13 to upgrade the lime kiln particulate control system, the plant considered a fabric filter as well as wet scrubber systems proposed by several vendors. The fabric filter alternative was rejected because the expected maintenance requirements were too great a burden on the small maintenance staff, because temperature control was expected to be a problem, and because the filter was expected to require more energy to operate than a scrubber. The existing multiple cyclones had required a 250-hp fan, and a fabric filter required a 450-hp fan to handle kiln exhausts plus dilution air for protecting the filter fabric from high temperatures. The wet scrubber system that was eventually installed required a 200-hp fan.

The wet scrubber designs that were considered varied greatly in costs, delivery times, and materials of construction. One vendor recommended an expensive all-stainless-steel design (alloy 316L). Another vendor recommended that only part of the system be constructed of stainless steel; however, this vendor had such a backlog of orders, that it could not promise delivery for 2 years. Source 13 selected a third vendor who contended that a less expensive scrubber constructed of carbon steel would withstand any corrosive constituents in the exhaust gases because of the acid-neutralizing effects of the lime in the collected particulate. This vendor was also able to construct and deliver a scrubber without delay. This vendor had never designed a scrubber for a lime kiln, but offered an 18-month warranty with the system.

After the first series of corrosion failures in the carbon steel scrubber system, Source 13 could not get satisfactory response from the vendor concerning the warranty. At this point, the plant management investigated, for the first time, scrubber systems in other lime kiln applications. These investigations revealed that carbon steel is generally not acceptable for scrubbers serving coal-fired lime kilns.

Source 13 also had the kiln exhausts analyzed in two locations and the scrubbing liquors tested in three locations. These chemical analyses revealed that significant quantities of acid-forming gases were present in the exhausts. As would be expected in a coal-fired process, quantities of sulfur trioxide in the exhaust gases formed dilute sulfuric acid in the scrubbing liquors. Because the level of chlorides was found to be low, it seemed that stainless steel would be a suitable material. Because of the high level of excess combustion air used in the kiln, however, there were unusually high levels of nitrogen oxides in the gases. These formed high concentrations of nitric acid in the scrubbing liquors, eliminating the possibility of using less expensive 302 or 304 stainless steel alloys. Because of the nitric acid, the more expensive 316L alloys were required.

Chemical analysis of the scrubber gases and liquors also indicated that most of the alkaline constituents in the kiln exhaust gases were scrubbed out in the quench chamber. Approximately 70 percent of the particulate collected by the scrubber system appeared in the quench chamber outlet slurry and only 30 percent in the scrubber outlet slurry. Corrosion affected the scrubber but not the quench chamber because of this uneven distribution of lime-bearing materials in the slurries and because of a less violent mixing in the quench chamber. The water sprays in the quench chamber were able to scrub much of the alkaline particulate out of the flue gases, but allowed most acid-forming gases to pass into the scrubber. In the scrubber, a more violent mixing caused a greater transfer of the acids into the scrubbing liquor that contained the smaller quantity of alkalis.

The high water flow is necessary in the quench chamber to prevent solids deposition and plugging within the vessel. Even with this high water flow, the vessel must be cleaned frequently. Attempts to recycle the scrubbing liquors have not been successful because of plugging in the piping and pumps.

Source 13 regrets the purchase of the original scrubber system, because of the vendor's lack of experience in lime kiln scrubber applications and his recalcitrant attitude towards honoring the warranty. Management still feels, however, that a scrubber constructed of the proper alloys is the best alternative, because of the high particulate collection efficiency and the low maintenance costs. Plant management also feels that the State Agency complicated the decisionmaking process by requiring action in too brief a time period.

CORROSION-RELATED EMISSIONS AND COSTS

Corrosion-related excess emissions during the first year of scrubber operation occurred during approximately 50 bypass events. These bypass events were between 3 hours and 3 days in length. Based on the estimated uncontrolled emissions rate (Table A13-1), corrosion-related excess emissions during the first year of scrubber operation may have exceeded 20 Mg. Stack tests have shown that kiln emissions are below the regulatory limits of 13.6 kg/h when the scrubber is operating properly.

TABLE A13-1. PARTICULATE EMISSION RATES FOR SOURCE 13 LIME KILN

Uncontrolled emissions	>136 kg/h
Emissions from original settling chamber	>91 kg/h
Emissions from settling chamber followed by multiple cyclones	>27 kg/h
Mass emissions regulations	13.6 kg/h
Emissions from scrubber system	<13.6 kg/h

The costs of the scrubber corrosion have been substantial. The original carbon steel scrubber system cost $135,000 (1978 dollars). Source 13 has spent an additional $400,000 to repair and replace corroded scrubber components. The scrubber manufacturer has been reluctant to honor the equipment warranty and is still negotiating the warranty refund.

A greater cost to the plant has been the lost production during corrosion-related shutdowns. These have cost the plant an estimated $300,000 to $400,000. During the first 6 months of scrubber operation, the kiln was shut down approximately 30 percent of the time because of scrubber corrosion. In addition, the shutdown during the rebuilding of the scrubber lasted 6 weeks. The State Agency did not permit the plant to continue production using the scrubber bypass for a period of this length. An additional cost of the scrubber corrosion is a decrease in the life of the kiln refractory because of frequent startups and shutdowns. These costs cannot be precisely determined.

SOURCE 14

FABRIC FILTERS SERVING LIME KILNS

SUMMARY

This facility contains one rotary lime kiln and a battery of five shaft lime kilns. A fabric filter is used to remove particulate from the rotary-kiln exhaust gases, and a similar filter serves the five shaft kilns. Corrosion has not become a problem in the rotary kiln filter even though the kiln is fired with oil. The shaft-kiln filter is suffering severe corrosion, however, despite the use of natural gas as fuel. The determining factor in filter corrosion is not the fuel used, but the reliability of kiln exhaust gas temperature control. The batch-type shaft kiln process allows frequent periods of low exhaust gas temperatures, which promote moisture condensation on steel surfaces within the shaft kiln filter.

Corrosion in the shaft kiln filter has not yet resulted in the use of the filter emergency bypass. Filter efficiency, however, may have been reduced on occasion because of corrosion. The excess emissions attributable to reduced filter efficiency because of corrosion cannot be quantified. The costs of filter corrosion have included a modest amount in repair work at the filter access doors and a substantial decrease in the useful life of the filter.

SOURCE DESCRIPTION

Source 14 consists of one rotary lime kiln and five shaft lime kilns located at a limestone quarry. The rotary kiln is fired with No. 2 fuel oil and operates continuously. The five shaft kilns are fired with natural gas and operate intermittently.

Exhaust gases from the rotary kiln are treated for particulate removal by a 5-year old shaker-type fabric filter. The kiln is equipped with a heat exchanger to recover heat for preheating the limestone aggregate and to cool the exhaust gases from approximately 375°C to a temperature below the maximum safe temperature for the filter bag fabric.

Exhaust gases from the five shaft kilns are treated for particulate removal by a 4½-year old fabric filter similar to the one serving the rotary kiln. The shaft kiln exhausts are ducted to a common flue and then through a cooling loop that cools the gases from a maximum temperature of approximately 350°C to a temperature compatible with the filter bag fabric.

Both fabric filters are constructed of corrugated transite mounted to the outside of a carbon steel support structure. Filter hoppers are carbon steel with thermal insulation on the outside. Each filter is equipped with a temperature alarm that actuates when inlet gas temperatures reach 290°C. At the sounding of an alarm, plant personnel can divert gas flow through bypass dampers to protect the bag fabric from heat stress.

MALFUNCTIONS DUE TO CORROSION

Corrosion has varied markedly in the two fabric filters at Source 14. The filter serving the rotary kiln does not seem to be greatly affected by corrosion, but the filter serving the shaft kilns has suffered severe corrosion at the access doors (Figure A14-1). The structural supports are also suffering from corrosion, which will eventually threaten the structural integrity of the shaft kiln filter (Figure A14-2).

An additional materials problem in both filters is the inability of the filter compartment isolation dampers to seal individual compartments from the kiln exhaust gases. The isolation dampers are designed to allow maintenance activities within an individual compartment while the kilns are operating. Because of heat warpage, the dampers do not seal sufficiently to

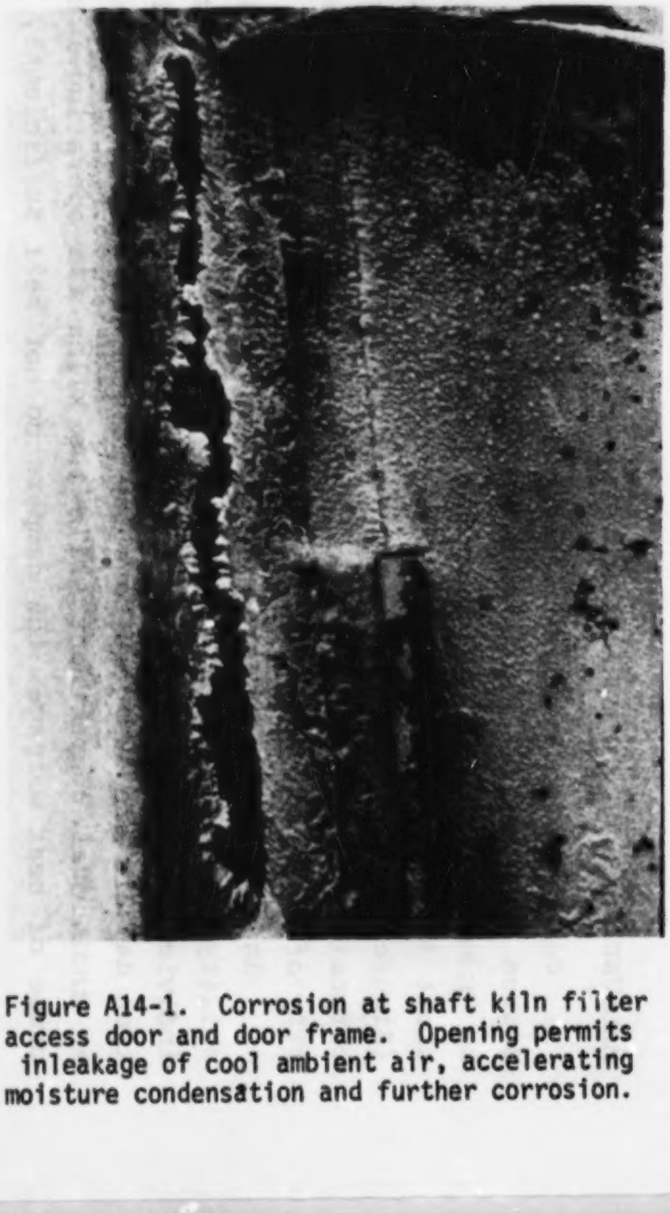


Figure A14-1. Corrosion at shaft kiln filter access door and door frame. Opening permits inleakage of cool ambient air, accelerating moisture condensation and further corrosion.

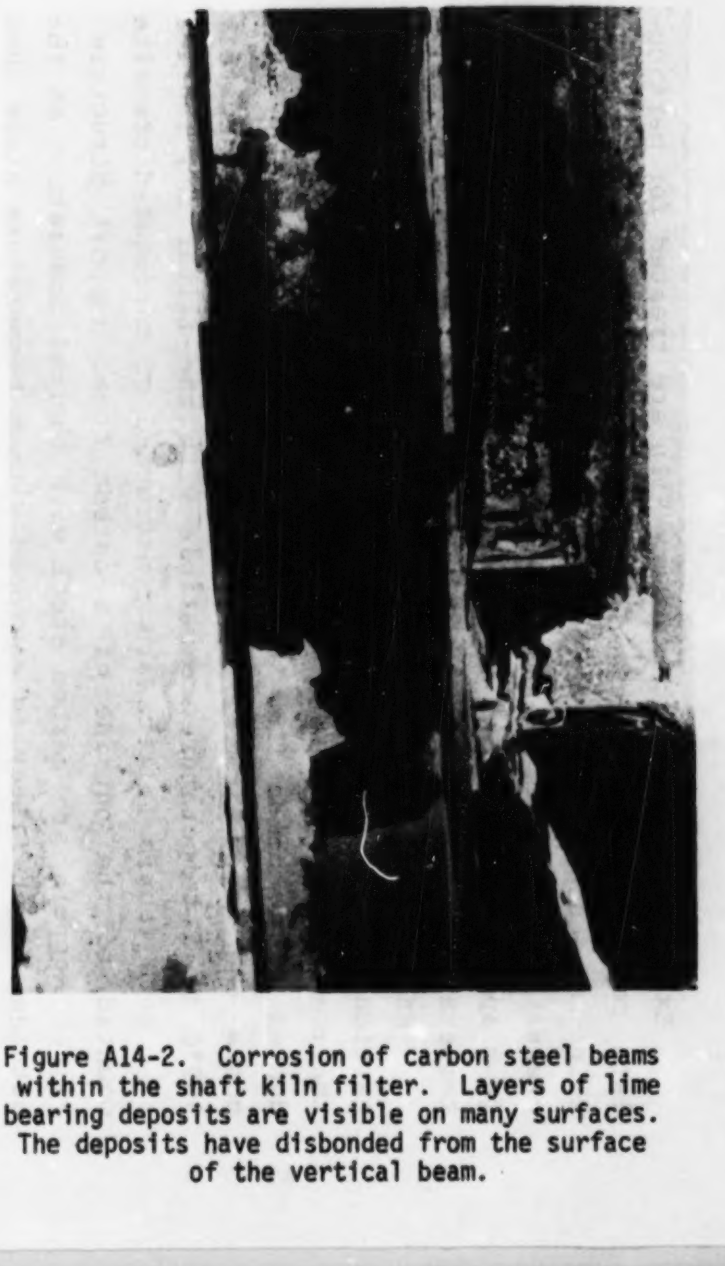


Figure A14-2. Corrosion of carbon steel beams within the shaft kiln filter. Layers of lime bearing deposits are visible on many surfaces. The deposits have disbonded from the surface of the vertical beam.

maintain a safe working environment in an isolated compartment. Corrosion of the dampers may also be contributing to this sealing problem.

DESIGN EVALUATION

The differences in corrosion rates in the two filters can be attributed to differences in inlet gas temperatures. Both filter systems are designed to handle exhaust gases with temperatures of approximately 230°C so that neither condensation nor heat stress of the fabric will occur. The continuously operated rotary kiln seems to produce exhaust gases that are consistently near the designed temperature. The temperature of the combined exhausts from the shaft kilns, however, varies considerably.

The shaft kilns operate in a batch fashion with frequent startups and shutdowns. The number of shaft kilns operating at a time can range from none to five. The cooling provided by the cooling loops can also vary, depending on the temperature of the ambient air. These factors combine to allow gas temperatures in the filter to fall so that moisture condensation on steel surfaces is frequent. Water vapor in the exhaust gases originates from the limestone feedstock to the kilns, from combustion air, and from the combustion of natural gas. Condensed water can absorb traces of sulfur trioxide that may be present in the exhaust gases and form dilute sulfuric acid (it is reported[1] that natural gas contains an average of 4.6 kg of sulfur per 10^6 m^3, and the limestone feedstock at Source 14 is reported to contain 0.02 percent sulfur).

Corrosion is most severe in the corners of the filter and at the uninsulated access doors, where exhaust gases are most likely to be cooler. Significant corrosion has not occurred in the insulated hoppers or in the warmer center of the filter. The high concentrations of lime in the collected dusts have not provided corrosion protection to the steel components. The lime-bearing dusts form a solid cake of material that disbonds from the steel surfaces (Figure A14-2). Disbonded lime cake may contribute to corrosion rather than mitigate it because moisture can condense more readily under the cake. The cake layer apparently insulates steel surfaces from the heat of the exhaust gases within the filter, and it prevents ventilation of the surfaces, which retards the drying of any condensed moisture.

CORROSION-RELATED EMISSIONS AND COSTS

Source 14 reported that corrosion in the fabric filters has not resulted in any filter bypass events. All corrosion-related maintenance has been accomplished during kiln shutdowns. It is possible that corrosion in the filter may have reduced filter efficiency on occasion. Air inleakage at corroded access doors may affect filter performance and isolation damper leakage may make speedy repair of broken bags impossible.

The costs of filter corrosion thus far have been limited to the costs of replacing corroded access doors and door frames. These costs have not been determined, but they are negligible in comparison to the total value of the filters ($500,000 each in 1975 dollars). The principal expense caused by filter corrosion is a decrease in filter life, which will necessitate early replacement of the shaft kiln filter. Source 14 had hoped to get at least 10 years of service from the filters, but the shaft kiln filter is not likely to last more than 7 years. The rotary kiln filter, however, will probably provide more than 10 years service.

REFERENCES

1. Compilation of Air Pollutant Emission Factors, Third Edition, EPA-AP-42, August 1977.

SOURCE 15

WET SCRUBBERS SERVING ROTARY LIME KILNS

SUMMARY

This facility operates three coal-fired rotary lime kilns that have a total of six wet-fan scrubbers for particulate control. During the first 5 years of service the carbon steel scrubbers have experienced corrosion, abrasion, and plugging problems. Sulfuric-acid corrosion has occurred in the demister sections of the scrubber vessels and in the scrubber stacks. Abrasion has occurred in the precleaner chambers of the scrubber vessels, where particulate loadings are the heaviest. Plugging has occurred in both the precleaner sections and in the scrubbing liquor piping.

No excess particulate emissions from any of the scrubbers can be attributed to corrosion. Scrubber performance, however, appears to be adversely affected by plugging problems. The costs of scrubber corrosion have totalled $30,000 (1979 dollars) for replacement of corroded stacks. Scrubber plugging has cost a significant, but undetermined, amount in lost production and labor.

SOURCE DESCRIPTION

Source 15 consists of three coal-fired rotary lime kilns located at a limestone quarry. Each kiln has two wet-fan scrubbers, arranged in parallel, for removing particulate from kiln exhausts (Figure A15-1). In the two larger kilns, the scrubber pairs are used simultaneously, while in the smallest kiln, the scrubbers are alternated.

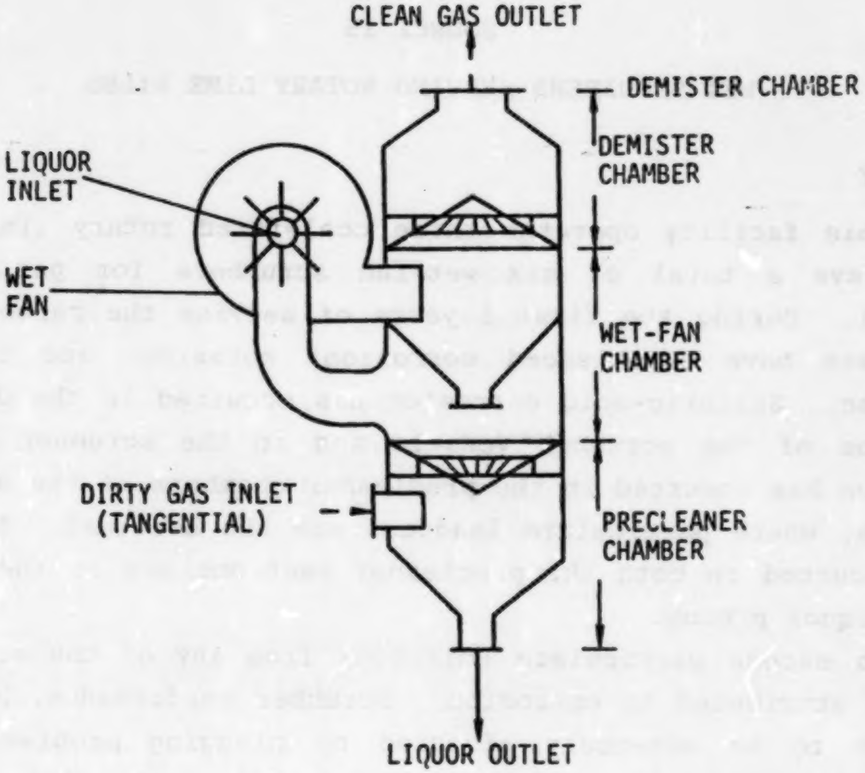

CLEAN GAS OUTLET
DEMISTER CHAMBER
LIQUOR INLET
DEMISTER CHAMBER
WET FAN
WET-FAN CHAMBER
DIRTY GAS INLET (TANGENTIAL)
PRECLEANER CHAMBER
LIQUOR OUTLET

Figure A15-1. Source 15 wet-fan scrubber.

Each scrubber contains three chambers: a tangential inlet, cyclonic precleaner chamber at the bottom of the vessel; a wet-fan chamber in the middle; and a centrifugal mist eliminator at the top. All scrubber vessel parts are carbon steel. The fan wheel is type 304 stainless steel and the fan housing is carbon steel. The scrubber stacks were originally carbon steel, but they are being replaced with type 304 stainless steel stacks.

Scrubber inlet gas temperatures vary between 425° and 540°C. The 112-kW fans provide a gas flow of 33 m^3/s (at 540°C) through each scrubber. Scrubber pumps can provide up to 4500 ℓ/min of water at a pressure of 700 kPa. Actual water use is not measured, but approximately 900 ℓ/min of particulate-laden slurry drains to the settling pond through 30 cm piping, but they now flow through an open flume. Detention time in the settling pond is 26 h.

MALFUNCTIONS DUE TO CORROSION

Corrosion first appeared in the carbon steel stacks immediately above the dampers. This corrosion progressed to the point where the stacks became structurally unsound and had to be removed. Portions of the scrubber stacks above the dampers were replaced with type 304 stainless steel. Four of these stacks have been removed because the portions below the dampers have continued to corrode and cannot safely support them (Figure A15-2).

Additional corrosion has occurred in the demister chamber of the scrubber vessel. Several small holes in the chamber walls have required patching and several hatches have required replacement (Figures A15-2 and A15-3).

Neither the lower two chambers, the fan, nor the slurry piping have suffered significant corrosion. The lower chamber, however, has been subject to abrasion and plugging. Within 3 months of scrubber startup, the walls of the lower chambers had been penetrated by particulate abrasion. Plant maintenance personnel have welded thicker carbon steel plate over the affected areas. Plugging has occurred in slurry outlet piping necessitating replacement with an open channel to facilitate frequent cleaning. Solids have also accumulated in the lower chamber of the scrubber, requiring frequent manual cleaning.

DESIGN EVALUATION

The original intention of Source 15 was to use a single scrubber for each kiln and to have the second scrubber as a

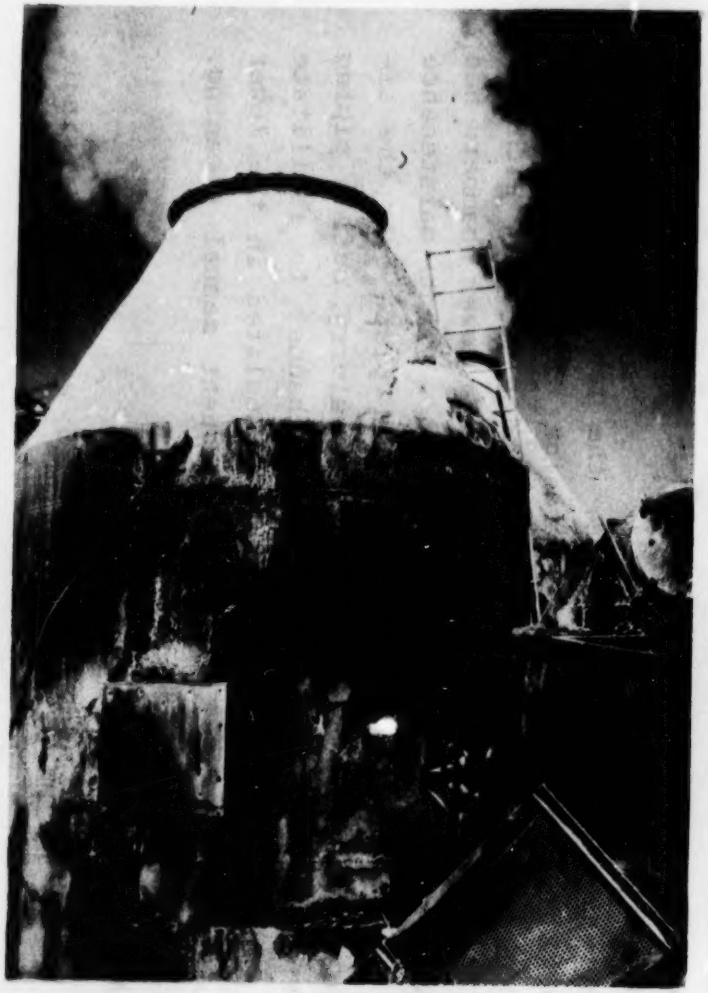


Figure A15-2. Two wet scrubbers in operation at Source 15. Stacks for both scrubbers have been removed because of corrosion. Hatch for entry into the demister section of the nearest scrubber has recently been replaced because of corrosion.

Figure A15-3. Entry hatch of a scrubber vessel showing leaks resulting from lime deposits and corrosion at the seal.

standby. This scheme would have permitted cleaning and other maintenance of the off-line scrubbers without interrupting production. After installation of the scrubbers, it became apparent that a single scrubber and fan would not provide sufficient gas flow through the larger kilns to maintain optimum production. Because of this, the plant had to abandon the alternating scrubber scheme, except on the smallest kiln. The plant now must run the two larger kilns for shorter campaigns than otherwise possible, because they must be shutdown frequently to allow the removal of solids from the scrubber vessels.

Prior to selecting the scrubber system, Source 15 invested little time investigating the materials of construction to be used. Plant management contends that the compliance schedule imposed by the State Agency left little time to adequately consider all aspects of scrubber design. The plant, which had been out of service briefly under previous ownership, was required by the State agency to submit completed emissions control plans prior to returning the kilns to production. The firm had several stainless steel scrubbers at another plant that were providing good service. Plant management, however, incorrectly concluded that these expensive materials of construction were not actually necessary in lime kiln service.

Corrosion in the Source 15 scrubbers appears in the upper chamber and in the stack because of acid mist (sulfuric acid and possibly nitric acid) formed by the mixing of the flue gases with the scrubbing water. Acids in the lower chambers and in the scrubber piping are neutralized by the heavy burden of lime-bearing particulate collected in the slurries. Liquors in the upper portions of the scrubber do not collect as much neutralizing materials. The sulfur and nitrogen oxides absorbed into these liquors form acids that are not completely neutralized.

The exterior surfaces of the carbon steel scrubber vessels are coated with a red lead primer that has remained intact. This coating, and the lime deposits that have formed from mist fallout from the plume and from leaks in the scrubber vessel and at plumbing fittings have prevented corrosion on most outer surfaces of the vessels. One noticeable exception is at areas just above leaking hatch seals.

CORROSION-RELATED EMISSIONS AND COSTS

Scrubber efficiency could not be estimated during the inspection. The two scrubbers that were operating, however, exhibited a light residual of particulate in the plume beyond the point of steam dissipation. As noted earlier, there was also evidence of poor mist elimination. Inspection of an out-of-service scrubber revealed severe solids buildup in the lower chamber and additional, less-severe buildup in other chambers. It appears that solids buildup, rather than corrosion, is the primary cause of any deteriorations in scrubber efficiencies.

Corrosion-related costs have been limited to the costs of replacing the six carbon steel scrubber stacks with type 304 stainless steel stacks after less than 5 years of service. (Designed life for scrubber components is 15 years.) The stainless steel stacks cost approximately $30,000 (1979 dollars). This represents an additional 12 percent in capital expenditures added to the original installed cost of the scrubber systems. There have been lost production costs due to plugging but none due to corrosion. The costs of repairing abrasion damage in the scrubbers are also undetermined.

SOURCE 16

FABRIC FILTER SERVING INDUSTRIAL BOILER

SUMMARY

This coal-fired boiler provides process steam to an industrial facility. Boiler particulate emissions have been controlled by a shaker-type fabric filter since 1974. After approximately 1 year of operation, acid-dewpoint corrosion, hopper plugging, excessive bag wear, and fan abrasion had combined to render the filter ineffective. Lack of thermal insulation and poor fan design were the principal causes of the filter system operation and maintenance problems.

Source 16 flue gases were bypassed around the disabled filter for most of a 4-year period beginning in 1975. Costs of repairs and modifications to the filter and the fan since start-up have totalled more than $300,000, which is more than the installation cost of the filter.

SOURCE DESCRIPTION

Source 16 is an industrial facility that uses several coal-fired boilers to provide process steam. Particulate emissions from one of the boilers are controlled by the fabric filter described in this report, and emissions from the others are controlled by venturi scrubbers. The boiler served by the fabric filter produces steam at the rate of 6.9 kg/s and uses coal that contains between 1 and 2½ percent sulfur and between 10 and 15 percent ash.

The retrofitted fabric filter is a four-compartment shaker-type, designed to handle 21.5 m^3/s of flue gases at 175°C. Cleaning cycles in the filter are timed by an electronic control system actuated by the filter differential manometers. At the time of installation, the filter was not insulated. Since that time, insulation has been added in stages to the shell and hoppers, and a wind screen has recently been added. Draft in the filter system is generated by a single inlet, high-speed fan located between the boiler and the filter. Because of its high rotation speeds and its location on the dirty side of the filter, the fan has surface-hardened Nibraze alloy steel to reduce abrasion wear.

MALFUNCTIONS DUE TO CORROSION

Corrosion became a problem in the filter within a year of installation. By 1975 corrosion failures and other maintenance problems had made the filter system so ineffective that it was removed from service. The filter was not in use during most of the period from 1975 through 1978.

Fan

A single-inlet, high-speed fan was selected for the filter system because of limited space between the boiler and the retrofitted filter. The fan's single-inlet design concentrates larger fly ash particulates to one side of the fan wheel where their high velocities cause severe abrasion (Figure A16-1). Maintenance personnel report that the fan will operate only 3 to 6 months before a major overhaul is required. Use of Nibraze alloy steel has not reduced wear to acceptable levels.

Dust Hoppers and Filter Shell

The mild steel dust hoppers and the filter shell exhibited signs of acid dewpoint corrosion within the first year of filter operation. In addition, the hoppers were subject to frequent plugging because of the condensed moisture. Insulation added to the hoppers and the filter shell was not sufficient to prevent flue gas temperatures from cooling to below the dewpoint within

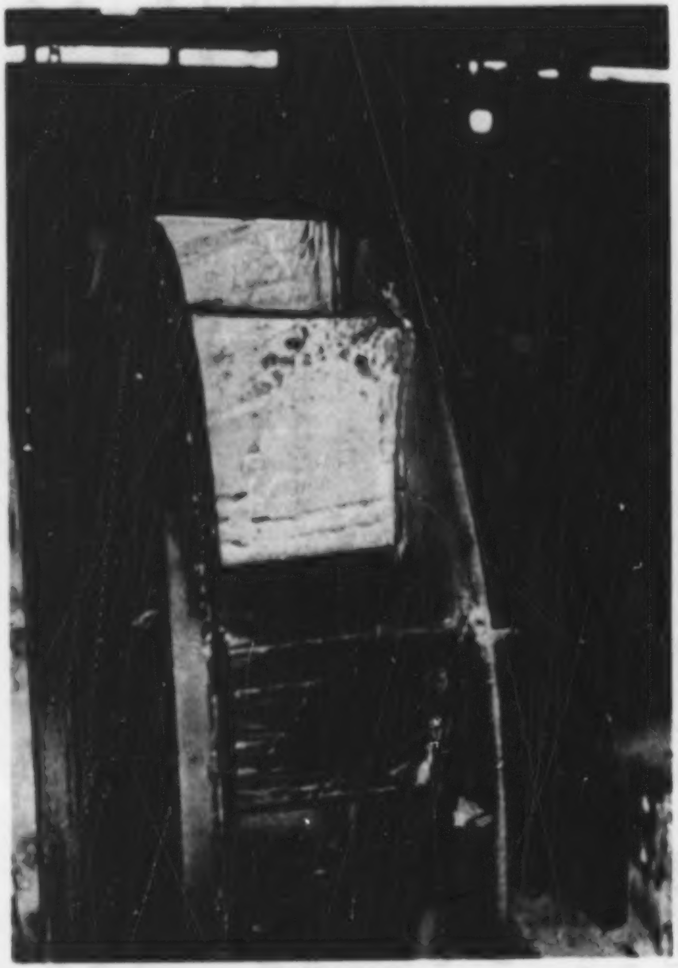


Figure A16-1a. Source 16 fan wheel (during overhaul) showing abrasion on blades.

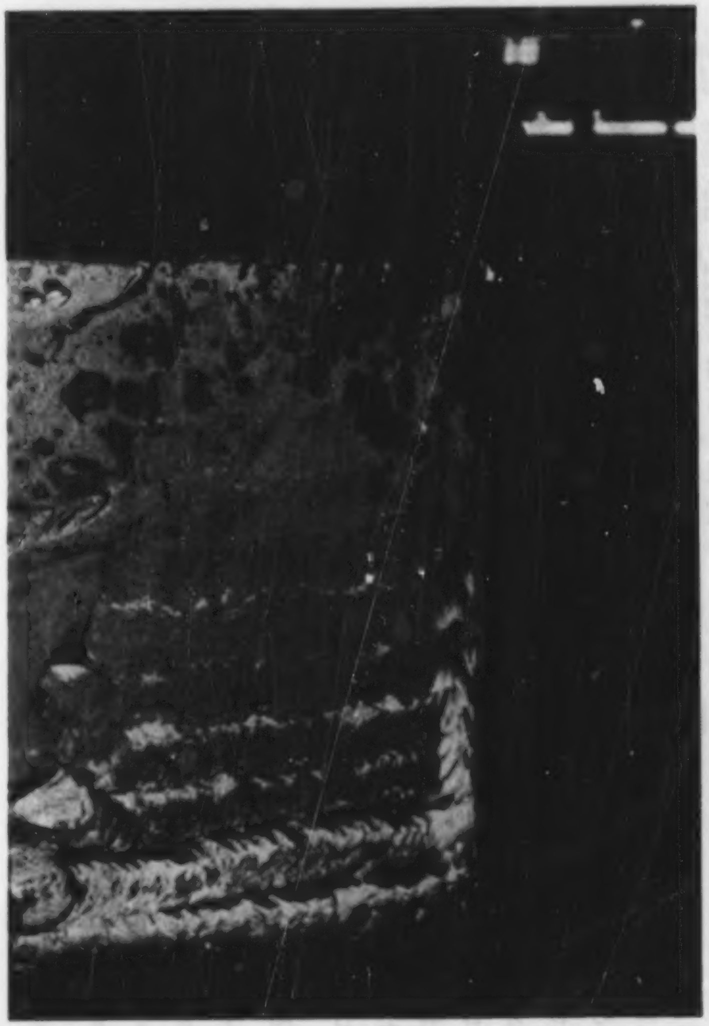


Figure A16-1b. Single blade of Source 16 fan wheel showing abraded channel along right side.

the filter. Insulation on the hoppers eventually became disbonded (Figure A16-2). Insulation on the filter shell was installed in such a manner that filter structural supports protruded through to ambient air (Figure A16-3). During the inspection, corrosion was especially apparent on interior filter walls along these cooler structural supports. These steel beams conduct heat from localized sections of the filter wall creating conditions conducive to acid condensation. By protruding through the insulation blanket, these beams can also channel rainwater to the filter walls.

Dampers

Dewpoint corrosion also occurred in the filter compartment dampers. These damper failures prevented proper sealing of individual compartments, preventing access to the filter for on-line maintenance.

Cleaning Mechanism Controls and Filter Instrumentation

The shaker mechanisms for cleaning the filter bags have suffered repeated malfunction because the electrical controls have corroded. Shaker-mechanism limit switches and fuses as well as filter instrumentation were not properly protected from the weather and therefore suffered atmospheric corrosion.

DESIGN EVALUATION

There are several design deficiencies in the Source 16 fabric filter. One deficiency is the excessive loss of heat that has led to the dewpoint corrosion. The original uninsulated design was grossly inadequate for maintaining temperatures above the dewpoint in the filter. Subsequent addition of insulation to the filter shell and the hoppers was only partially successful in preventing heat losses. Insulation on the hoppers did not remain intact and there were gaps in the shell insulation.

A second design deficiency is the location and size of the fan. The space available for a dirty side (forced draft) fan

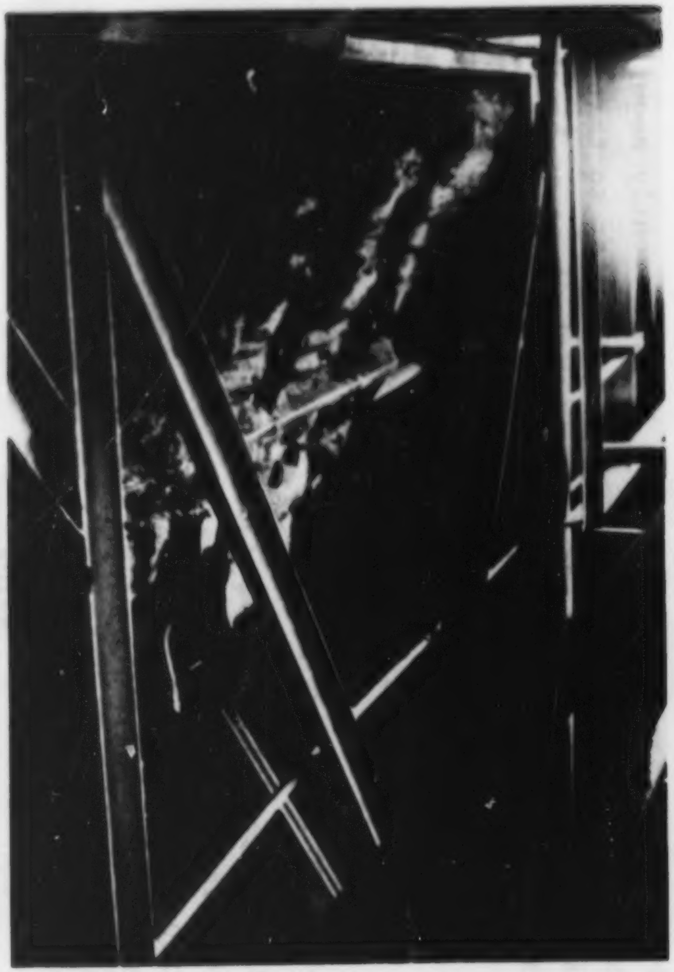


Figure A16-2. Thermal insulation on hopper of Source 16 filter showing large sections where insulation has become disbonded.

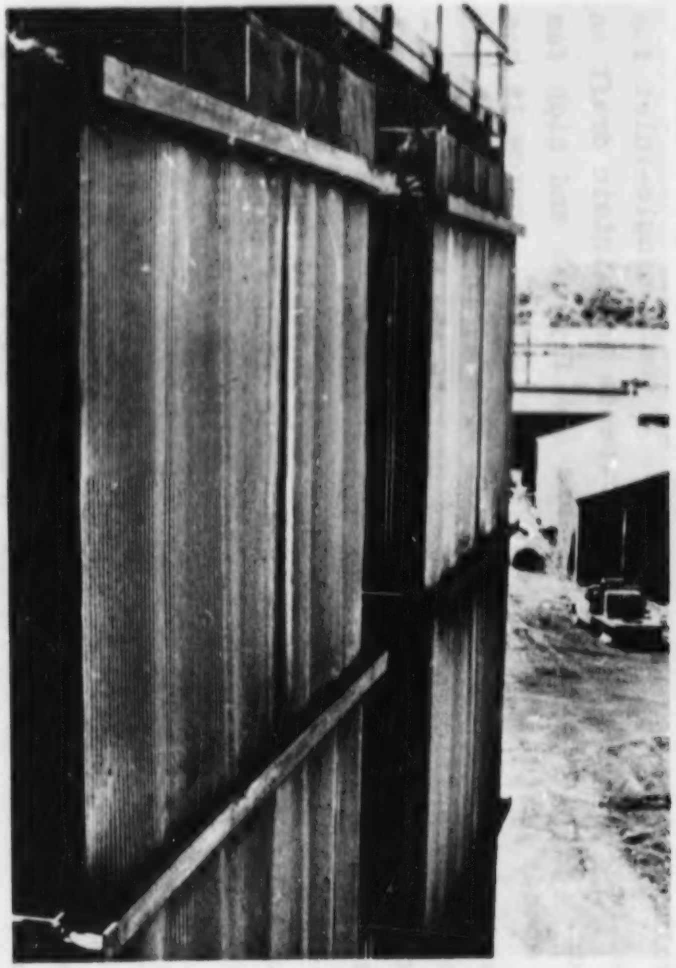


Figure A16-3. Exterior of Source 16 fabric filter showing structural steel protruding through the insulation blanket. The exposed structural steel promotes cold spots within the filter and may also channel rainwater under the insulation blanket.

after retrofitting the filter to the boiler was quite limited. As a result, Source 16 had to install a small single-inlet fan which must be operated at very high speeds to maintain draft on the boiler. The combination of abrasive fly ash and high fan rotation speeds has made fan abrasion inevitable. Source 16 has also indicated that, despite high fan speeds, the filter system has not provided sufficient draft to operate the boiler at maximum capacity. Source 16 should consider replacing the forced draft fan with a larger, slower speed induced draft fan, if economically feasible. Although this design would require a new stack and additional ductwork and would reduce space in the plant yard, it could eliminate fan abrasion and boiler draft problems.

A third design deficiency in the filter is that the filter bags suffer premature failure because of excessive bag abrasion at the bag inlets. Possible solutions to this problem include changes in inlet design to include a wear plate or a wear thimble, or the use of cyclone precleaners to remove abrasive heavy particulates. The latter change could also reduce fan abrasion, but it is doubtful that space is available for precleaner devices.

The boiler superintendent at Source 16 has recently begun a step-by-step program to repair and modify the filter so that it will operate for extended periods of time without major breakdowns. The first steps have been to repair corroded shaker mechanism electrical components and to erect a windscreen to further reduce filter heat losses. Other measures may include improving existing insulation and adding heaters to the hoppers.

CORROSION-RELATED EMISSIONS AND COSTS

Based on reported emission factors,[1] uncontrolled boiler particulate emissions at Source 16 are likely to be in the range of 90 to 230 kg/h depending on the boiler firing rate and the ash content of the coal. During most of the 4-year period beginning in 1975, boiler exhausts bypassed the inoperative fabric filter. The exact quantity of particulate emissions resulting from the uncontrolled conditions is unknown because the boiler operating schedule, firing rate, and coal ash content are not readily available.

Installed costs for the filter were about $250,000. Repairs since filter startup have amounted to nearly $250,000. Source 16 has also spent an estimated $30,000 to $40,000 annually on fan and duct repair.

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SOURCE 17

VENTURI SCRUBBER SERVING COAL-FIRED INDUSTRIAL BOILERS

SUMMARY

This industrial facility operates three coal-fired boilers to provide steam for various plant processes and for winter heating. Exhausts from the boilers pass through a retrofitted venturi scrubber for particulate removal. The scrubber was first constructed of 304 stainless steel, which failed catastrophically within 2 months. The replacement scrubber was constructed of fiberglass-reinforced plastic (FRP), which has given satisfactory service for 6 years. However, several bolts and a refractory-lined carbon steel quench chamber in the new scrubber system have experienced corrosion problems; these items were replaced with Carpenter 20 stainless steel.

The failure of the original scrubber caused a $140,000 financial loss to the source and the manufacturer and caused the plant to operate uncontrolled for a year longer than specified in the compliance schedule. The responsibility for the incorrect choice of materials must be shared by the State Agency as well as by the source and the scrubber manufacturer. The State forced an unrealistic compliance schedule (5 months) on the plant management only weeks after the facility had changed ownership; thus, the plant had no time to perform a complete engineering analysis of the problem and had little time to purchase and install the control device.

SOURCE DESCRIPTION

This facility uses three 6.3-kg/s boilers to provide process steam and plant heating. No more than two boilers are used at a time; the third is maintained as a standby. Typically, the two operating boilers are fired with low-sulfur Appalachian coal producing a combined steam rate of about 8.8 kg/s.

Prior to 1971, the plant operated the three boilers without any control of particulate emissions. Because the plant owners were planning to close the plant, the State Agency took little interest in the facility. In 1971, the present owners acquired the plant. Shortly thereafter, the State Agency imposed a compliance schedule on the plant that required installation of particulate controls within 5 months. Four scrubber manufacturers submitted bids; three of the four recommended 316L stainless steel as the main construction material, and one recommended 304 stainless steel. The latter, who had experience in the wet scrubbing industry, claimed that 304 stainless steel would perform just as well as 316L stainless steel and that it would cost significantly less. Consequently, the plant installed the venturi scrubber made of 304 stainless steel.

The scrubber vessel was designed as a 3.6-m diameter cylinder. Dirty air that entered the side of the vessel was forced through a 2.5-cm annular venturi opening formed by a conical skirt inside the vessel. The boiler flue gases passed through this venturi opening into a pool of scrubbing water where gas turbulence caused impaction of particulates by the water. Cleaned flue gases passed out of the water through radial vanes in the top of the scrubber vessel which imparted cyclonic motion to the gases and caused the droplets of scrubbing water to collect on the vessel sides. These scrubbed gases exited from this demister section through a stack on top of the scrubber, and the collected scrubbing water drained back into the bottom of the vessel. The scrubber used once-through municipal water as the scrubbing medium. The plant engineer reports that the pH of the water exiting the scrubber was approximately 2.0.

The design of the replacement scrubber was nearly identical to that of the original scrubber, but the material of construction was FRP instead of stainless steel. Because FRP materials were used, the flue gases had to be cooled before they entered into the scrubber. Consequently, a refractory-lined, mild-steel quench chamber was installed upstream of the FRP scrubber.

The new scrubber uses 227 ℓ/min of municipal water; of this, 76 ℓ/min evaporates and 201 ℓ/min are discharged with the plant wastewater. The water is not recycled, and there is no pH control in the system.

The scrubber typically handles about 31 m^3/s of flue gases. The pressure drop across the scrubber averages about 2.7 kPa. A bypass damper can direct the flue gases around the scrubber system to the old plant stack. The bypass is designed to activate whenever the instrumentation detects a temperature excursion in the scrubber, a loss of water in the scrubber, a loss of water flow to the system, or an unusual pressure differential across the scrubber.

MALFUNCTIONS DUE TO CORROSION

Stainless Steel Scrubber

Within 2 months after startup, the 304 stainless steel scrubber was removed from service because of severe corrosion. All internal surfaces of the scrubber had been attacked by the acidic scrubbing water (Figure A17-1). Corrosion was particularly severe on the venturi cone. The bottom of the skirt that formed the venturi cone had disintegrated (Figure A17-2) and caused a major loss of scrubbing efficiency. The corrosion of the venturi skirt was probably accelerated by the turbulent conditions in the venturi zone, which rapidly removed the corrosion products and thereby exposed new metal to attack.

FRP Scrubber

The FRP scrubber, which provided better service, has also experienced some corrosion problems. Originally, the scrubber internals and the vessel were bolted together with 316L stainless steel bolts; these failed after 6 months of service and were replaced with bolts made from Carpenter 20 stainless steel.

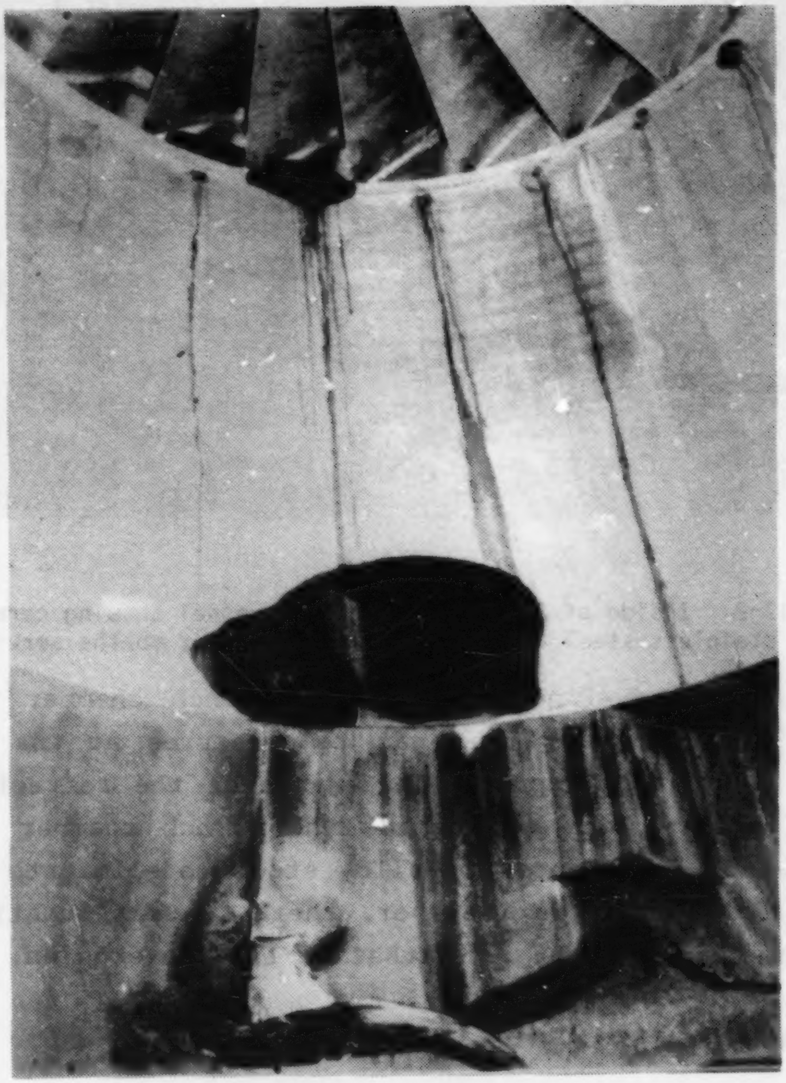

Figure A17-1. Inside of Source 17 scrubber vessel showing (from top to bottom) corrosion of 304 stainless steel rotating vanes, vessel wall, and venturi skirt after only 2 months service.

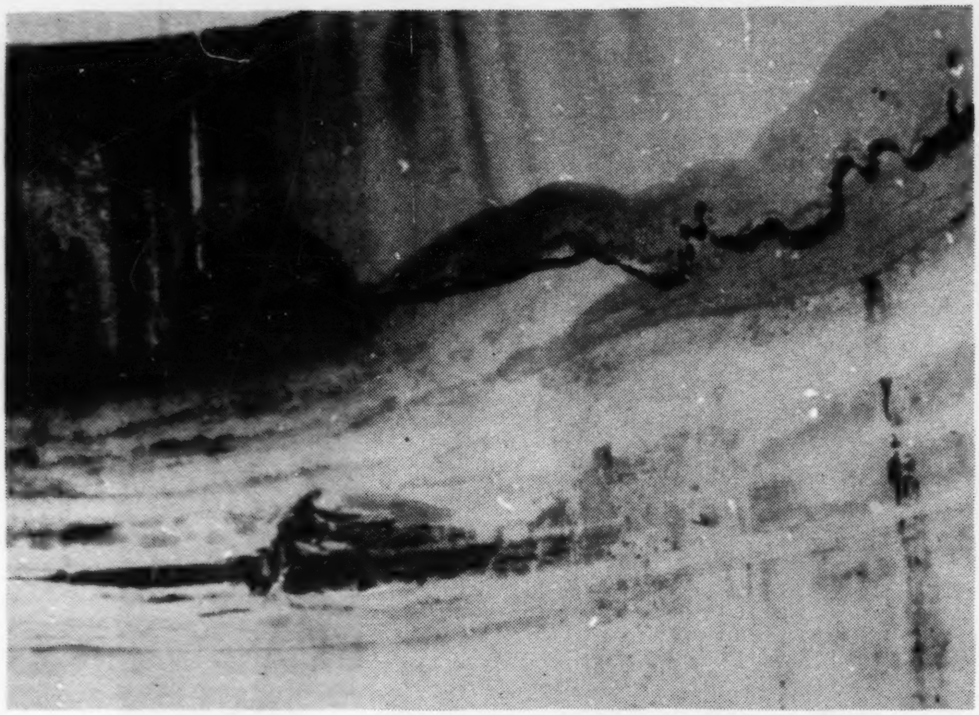

Figure A17-2. Inside of Source 17 scrubbing vessel showing corrosion of 304 stainless steel venturi skirt after only 2 months service.

The refractory-lined, mild-steel quench chamber that was installed to lower the flue gas temperatures at the scrubber inlet has required frequent maintenance of the refractory lining. The plant plans to replace the quench chamber with one constructed from Carpenter 20 alloy steel to eliminate the need for periodic maintenance; however, there is some question about whether the Carpenter 20 can withstand fly ash erosion.

DESIGN EVALUATION

Process Characteristics

The stoker-type boilers produce flue gases containing normal coal combustion products such as carbon dioxide, sulfur oxides, nitrogen oxides, and fly ash. When these gases contact water, they form corrosive agents such as sulfurous acid. The use of low-sulfur coal produces lower concentrations of the sulfur species than the use of high-sulfur coal, but the flue gases still contain enough sulfur oxides to be quite corrosive in a wet environment. The plant engineer reported that the pH of scrubbing water is sometimes as low as 2.0 with low-sulfur coal. Coal can also contain up to 0.5 percent chlorides.[1,2] These chlorides are volatilized during combustion,[3] and can be detrimental to most stainless steels.[4]

In summary, the environment produced by boiler flue gases in a scrubber is extremely corrosive to mild steel and can be corrosive to 304 and 316L stainless steels. The addition of a pH buffer system to the scrubber might have alleviated much of the corrosion, but such a system would increase the operating costs and would require frequent maintenance.

Materials of Construction

Selection of the original scrubber materials was based on misleading advice from the scrubber manufacturer, who claimed to have experience in manufacturing wet scrubbers. The manufacturer reasoned that the success of 304 stainless steel in other applications assured success in the scrubber for Source 17; unfortunately the manufacturer neglected to determine the specific chemical constituents of the fly ash and the flue gases to determine their compatibilities with 304 stainless steel.

Several other manufacturers advised the source that type 316L stainless steel would be an appropriate material. As indicated by subsequent corrosion of 316L bolts in the FRP scrubber, it is doubtful that these recommendations were sound.

The use of FRP for the second scrubber has proven to be appropriate. During the 6 years since installation, there have been no failures of the venturi skirt or any other FRP component. Compared with stainless steel, FRP has had one disadvantage--a low tolerance of the polyester resin to heat; this characteristic required the installation of the quench chamber, which increased system maintenance requirements.

CORROSION-RELATED EMISSIONS AND COSTS

Corrosion failures in the original scrubber resulted in about 1 year of additional uncontrolled boiler emissions. Corrosion failures in the replacement scrubber system (e.g., corroded bolts and eroded refractory lining) have not resulted in increased emissions, and they were corrected during routine maintenance.

The costs of the problems with the first scrubber were reported by the plant engineer to be $140,000 (1972 dollars) in materials and labor; these costs were shared by the source and the equipment manufacturer. The costs of materials failures in the replacement system cannot be accurately determined since they were part of the overall maintenance costs. Source 17 incurred no loss-of-production costs due to scrubber corrosion, because the enforcement agency permitted the source to operate uncontrolled after major equipment failures.

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SOURCE 18

WIRE-BURNING INCINERATOR CONTROLLED BY WET SCRUBBER

SUMMARY

This facility is a metals recycling plant that used a wire-burning incinerator to burn insulation from copper and lead-sheathed wires. Emissions from the incinerator were controlled by a wet scrubber that used sodium hydroxide for pH control.

Severe corrosion of the stainless steel scrubber stack and general operating problems with the scrubber resulted in the shutdown of the system after a limited life of 1 year. The principal reason for the corrosion of the stainless steel was hydrochloric acid in the incinerator flue gases arising from the combustion of polyvinyl chloride (PVC) and chlorinated rubbers. Although there were no uncontrolled emissions resulted from the corrosion of the scrubber system, the plant suffered a major financial setback because of the damage to the stack and the lost production resulting from shutdown of the system.

SOURCE DESCRIPTION

The wire-burning incinerator at this source used a wet scrubber to control particulate emissions. The incinerator was put into operation in 1976 to burn the coatings from copper wires so that the scrap copper could be recovered. The incinerator was intended for use on cloth, polyethylene, and other nonchloride-bearing insulation. However, all types of coated wire were fed to the incinerator including PVC and chlorinated rubber-coated wire and lead-sheathed cables. The incinerator operated on a batch basis, as needed.

From the incinerator, the flue gases were drawn through a dry fan to the scrubber. The scrubber, which was constructed from 316L stainless steel, used 38 ℓ/min of recirculated water. Sodium hydroxide was used to control pH; additions were based on hourly measurements using pH paper. The water was recirculated in copper pipes.

Flue gases from the scrubber passed to the stack. The lower 6.1 m of stack was designed with a double shell and an air anulus; reportedly, stainless steel was the material of construction. The upper portion of the stack (about 4.5 to 6.1 m) was a single shell design also fabricated from stainless steel.

MALFUNCTIONS DUE TO CORROSION

Fan

The fan, which is forced draft with respect to the scrubber, operated at a temperature above the dewpoint and did not have any corrosion problems.

Scrubber Shell, Internals and Pipework

In the 1 year of operation, corrosion problems did not occur in the scrubber or associated pipework.

Stack

The upper stack, which was fabricated from stainless steel (304 or 316), was subject to severe corrosion that weakened its structure and necessitated its removal after a service life of only 1 year. Attack initiated at welds but eventually spread to the plates. Inspection of the upper stack was not possible because the stack had been removed from the site.

The lower portion of the stack tc just above the roof line was still in place. Visual inspection found it to be of a double-shell design. The inner surface that contacted the flue gas was coated with a bitumastic lining. The lining appeared to be in good condition. The outer surface of the stack and the surfaces facing the air space of the anulus were uncoated and were badly corroded. Support brackets between the inner and outer shell had failed because of corrosion (Figure A18-1). The corrosion had caused significant thinning of the stack walls.

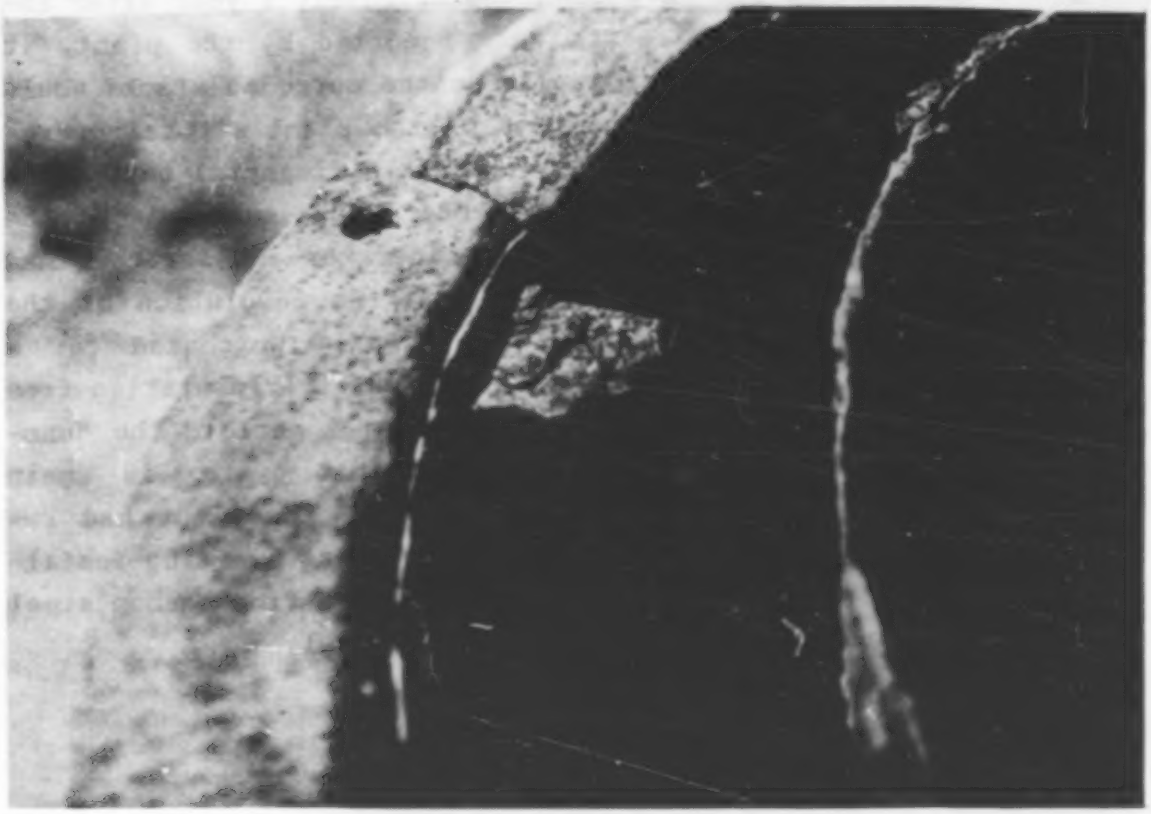

Figure A18-1. The double-wall structure of the lower portions of the stack. Note failed support bracket and general corrosion.

DESIGN EVALUATION

Materials of Construction

The combustion of PVC and chlorinated rubbers generates hydrochloric acid that can be particularly deleterious to stainless steels. The use of sodium hydroxide to control the pH of the recirculating water has protected the components of the scrubber, but the stack has been subject to severe corrosion. Presumably the scrubber is not totally effective in removing the acidic gases from the flue gases.

CORROSION-RELATED EMISSIONS AND COSTS

Corrosion and operating problems with the pollution control system resulted in its shut down approximately 1 year after installation. Although no costs were reported by the plant, it was clear that the costs of replacing the corroded stacks would represent a significant percentage of the plant's total operating costs. The plant attempted to seek a financial settlement with the scrubber manufacturer, but had little success. At the time the plant was inspected, the incinerator and scrubber had been shut down for almost 2 years awaiting resolution of the scrubber problems. The plant has recently purchased (at a significant cost) a machine designed to cut the insulation from the copper and lead wire. This machine will perform the functions of the incinerator system until that system is again operative. At the time of the inspection, the plant had received sections of a replacement stack that was awaiting installation. The replacement stack was fabricated from carbon steel lined with about 5 cm of a gunite-type material.

APPENDIX B: REVIEW OF LITERATURE ON CORROSION IN AIR POLLUTION CONTROL EQUIPMENT

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Keyword: cathodic protection, cladding, corrosion fundamentals, protective coatings

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Keyword: scrubbers (FGD)

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Keyword: acid dewpoint, dust hoppers, electrostatic precipitators, fabric filters, protective coatings

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Keyword: scrubbers (FGD), smelters, stainless steels

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Keyword: protective coatings, water treatment

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Keyword: aluminum alloys, cement plants, electrostatic precipitators

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Keyword: electrostatic precipitators, paper mills

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